CONTRIBUTIONS TO INFORMATION REQUIREMENTS FOR THE IMPLEMENTATION OF RESOURCE DIRECTED MEASURES FOR ESTUARIES

Volume 1

Improving the biodiversity importance rating of South African estuaries

J Turpie • B Clark • D Knox • P Martin •
C Pemberton • C Savy

WRC Report No. 1247/1/04

Water Research Commission

Contributions to Information Requirements for the Implementation of Resource Directed Measures for Estuaries

Volume 1
Improving the biodiversity importance rating of South African estuaries

REPORT TO THE WATER RESEARCH COMMISSION

BY

THE CONSORTIUM FOR ESTUARINE RESEARCH AND MANAGEMENT

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EXECUTIVE SUMMARY

The aim of this programme was to provide data and understanding to support the estuarine component of the Resource Directed Measures programme of the Department of Water Affairs and Forestry. This was a multidisciplinary programme of the Consortium for Estuarine Research and Management (CERM). The Amazon sub-committee of CERM administered the project. There were three projects that are reported in Volume 1 (Project 1) and Volume 2 (Project 3). Project 2 is reported on a CD as Volume 3. The capacity building and technology transfer components of the study are reported on in the Executive Summary.

PROJECT OBJECTIVES

Project 1: Improving the biodiversity importance rating of SA estuaries (Volume 1).

1. Improvement of existing database through collation of existing data.
   Recent Co-ordinated Water Bird counts (CWAC) were entered in a database. Recent fish data were identified but were not included due to the expense. Existing invertebrate data for all estuaries were collated in an excel database.

2. Filling information gaps with field work : summer bird counts in Wild Coast estuaries.
   Birds were counted in 67 estuaries along the Transkei coast in January-February 2002. A total of 2206 waterbirds and 40 waterbird species were recorded in the estuaries. Excluding terns, only 983 birds were counted in estuaries in total. Mangrove estuaries tended to have higher numbers of waders, and of birds in general. Ordination and multi-dimensional scaling analysis did not reveal any significant patterns in bird communities within the Transkei estuaries. Indeed, even though permanently open estuaries had more intertidal area, they did not support much higher numbers or variety of waders, as might have been expected. There was no major change in the importance ratings of Transkei estuaries as a result of the data generated in this study, due to the small numbers of birds involved. However, the importance ratings for Transkei estuaries are now accurately known, and a few of the larger estuaries are expected to be fairly important for birds, especially those supporting rare species such as Mangrove Kingfisher.

3. Predictors of biodiversity.
   This research is reported on in three chapters in Volume 1:
   - *A field study of the intertidal invertebrate fauna of 16 warm temperate estuaries.*
   - *Predicting invertebrate species richness on the basis of broadscale estuary characteristics*

   Meetings were held with team members and other interested parties on the selection of estuaries for study and the methodology, as well as the emphasis of the study. Due to budget constraints field sampling only took place in the warm temperate zone. Intertidal invertebrates were sampled *in 16 estuaries. This project has shown that each estuary is highly unique in character and that intertidal invertebrate communities are distinct and cannot be accurately predicted on the basis of simple environmental measures. A large proportion of species recorded were only present in one or two of the estuaries sampled. Species richness per estuary was the most predictable attribute and was strongly correlated with the slope of the river and estuary mouth condition.*

The study then attempted to develop a predictive model for invertebrate species richness for all estuaries using available data on some warm temperate estuaries. The variables considered were those that are readily available for most South African estuaries. Some 538 invertebrate taxa have been recorded in South African estuaries. These were separated by habitat into intertidal benthic, subtidal benthic and planktonic invertebrates.

This study is the first attempt at collating the invertebrate data of all South African estuaries, and provides new insight into the relative contribution that these sub-communities make to estuarine biodiversity. The research found that there is relatively little overlap between species recorded in the plankton, subtidal and intertidal macrobenthos and suggests that data on invertebrate biodiversity for only one or two of these groups would not adequately represent the biodiversity of an estuary.

Significant regression models were obtained for total species richness and subtidal benthic species richness. Subtidal species richness was significantly correlated with the area of submerged macrophytes (typically eelgrass Zostera capensis*), and the area of mangroves. When estuary types were analysed separately subtidal species richness was significantly correlated with mean annual runoff in both cases.*

For warm temperate permanently and temporarily open estuaries, species richness as a proportion of the 'species pool' was significantly positively correlated with estuary size. The research thus showed that estuary size is the most important variable determining the number of potential species that actually occur in an estuary. Estuary size is correlated with habitat area, habitat diversity and estuary type (i.e. permanently open estuaries are larger than others). The predictive equations for invertebrate species richness were used to determine estuarine importance scores for all South African estuaries. In the revised importance rating there was no correlation between the new scores and the old invertebrate scores, further supporting earlier concerns that the original index was inadequate.

4. Updating the importance rating of all South African estuaries.
   Existing and field study data were used to produce an updated importance rating database for South African estuaries. Despite the radical changes in the invertebrate importance scores and the significant changes in the bird importance scores, the overall ratings of estuaries were not greatly affected.

Project 2: Quantifying water quality changes that affect different taxa (submitted as a CD).

Quantitative information on the response of estuarine taxa to changes in water quality was collated. A CD has been compiled containing the data (tolerance bands and exposure times) and information tables in MS Excel format. The CD is available for use in future Resource Directed Measures studies. The data are contained in the directory, ***Estuarine Water Quality Database****, Each biotic group is in a sub-directory, microalgae, macrophytes, invertebrates and fish. Each constituent is in a separate file in the sub-directories e.g. salinity.xls, dissolved oxygen.xls. This format has been used so that the information can be updated easily and transferred into a database format. The system variables considered were salinity, turbidity/suspended solids and dissolved oxygen. For the microalgae temperature and pH were also included. Inorganic nitrogen, phosphate and ammonium were the nutrients considered. The effect of toxic substances (e.g. trace metals) was only considered for invertebrates and fish.*

Project 3: Responses of the biological communities to flow variation and mouth state in in two KwaZulu-Natal temporarily open – closed estuaries. (Importance of the river-estuary interface zone in temporarily open / closed estuaries – Volume 2).

1. Literature review.

The literature review by Perissinotto et al. *on the "Ecology of South African temporarily open/closed estuaries: a review of current knowledge" was e-mailed to the CERM members for input. After the inclusion of relevant inputs this review paper was submitted to the Journal of Marine Systems for possible publication. The aim of the synthesis was to provide an overview of the existing knowledge on the major biological, physical, chemical and management issues that affect dynamics of these key but highly threatened ecosystems.*

2. Quantifying the response of the biota to changes in flow and mouth condition.

The Consortium for Estuarine Research and Management held a workshop on 24 October 2001 at the University of Natal, Durban, to discuss the terms of reference and hypotheses for the study, and to select a research team. The Mdloti and Mhlanga estuaries were chosen as the study sites and the research team consisted of participants from the University of Natal, Durban and the CSIR, Durban with Prof Renzo Perissinotto as the project leader. Monthly sampling was conducted from March 2002 to March 2003 for physico-chemical, microalgal and zooplankton measurements. Macrobenthos, fish and birds were sampled quarterly. An unusual rainfall pattern was observed during the year of this study, with anomalous high precipitation recorded during the winter (July 2002). In terms of breaching events, 13 of these were recorded at the Mhlanga and 9 at the Mdloti. The study showed that provided the flows are sufficient to sustain residence times of the order of 1-2 days, then the mouth will stay open.

The original hypotheses proposed for the study were that during the open phase of the mouth, a river-estuary interface zone is established that is characterized by higher biodiversity and biomass *compared to the closed phase of the mouth and that biotic communities in the REI zone during the open phase of the mouth are distinct from downstream communities. These hypotheses were revised as KwaZulu-Natal estuaries are perched which prevents a distinct REI zone from forming.*

The study showed that during the open phase there was strong freshwater inflow followed by low water levels. Highest biodiversity and biomass occurred when the mouth was closed (phytoplankton, microphytobenthos, zooplankton). The maximum microphytobenthos biomass (601 mg chl-a.m^{-2}) occurred in December 2002, after a period of closure of about 15 days. Zooplankon (copepod nauplii) attained peak levels within 2 to 4 weeks following a rainfall event, with temperature and state of the mouth being the main factors controlling the delay in this response. The study hypotheses for macrobenthos (i.e. a different fauna develops after the open state with filter feeders becoming dominant due to food availability three months after mouth closure) could not be tested because there was no unbroken three month closure period. The open mouth state did not increase the diversity of birds as much of the areas exposed after breaching became supratidal rather than intertidal and the drier habitats did not support any of the small, shallow-burrowing prey species.

Many of the study hypotheses were focussed on freshwater input and its importance in introducing nutrients and stimulating biotic response. However both the Mdloti and Mhlanga estuaries receive treated sewage effluent and therefore available nutrients were never a problem. Indeed the Mhlanga Estuary was found to be eutrophic. Phytoplankton biomass was 303 mg chl-a m^{-3} in the lower reaches of the estuary in October 2002, this is the highest reported for any South African estuary. The hypotheses also focussed on the importance of mouth opening in stimulating biotic response. In both estuaries mouth breaching occurred regularly due to increased flow from the sewage plants, and the question is rather not how frequently the mouth should open in a year, but rather how long the mouth should remain closed. Frequent breaching results in a disturbed system where biomass can never build up.

Another important hypothesis that was tested was that overtopping of the berm is important for the recruitment of estuarine dependent invertebrates and fish. Overtopping was indirectly demonstrated, when six 20 mm Diplodus sargus *were netted in the Mhlanga while storm-swell overtopping was occurring (September 2002). Direct, conclusive evidence of recruitment through wave overtopping was obtained at the Mhlanga where juveniles of three fish species were netted in the incoming waves at the peak of the spring high tide in August and September 2003. The berm overtopping study showed minimal recruitment of invertebrates during the closed phase as only a few ghost crabs, mole crabs, nematodes and siphonophorans were collected during the six sampling exercises at Mhlanga and the two exercises at the Mdloti Estuary.*

Recruitment of juvenile fish and invertebrates via berm overtopping appears to be relatively small at the estuaries studied. Coarse sediments with steep, exposed beaches characterize them. Conversely KZN South Coast estuaries e.g. Lovu, Msimbazi, have finer sediments, and less steep *beach slopes. Here recruitment via overtopping was observed repeatedly and on a much larger scale than at the Mhlanga/Mdloti estuaries.*

One component of the study that was not addressed was the short-term responses of microalgae and zooplankton to the closing of the mouth. The objective of this investigation was to provide information on the time-scale of recovery of the primary producers and consumers after a mouth-breaching event and re-closure of the estuary. By December 2003 the mouth had not breached and therefore this component of the study could not be included in the final report

Capacity building

Resource Directed Measures (RDM) workshops

The objective of this component of the programme was to organise workshops on the RDM methodology to increase the pool of experts capable of doing this work. A workshop was held in Port Elizabeth in June 2002. Participants included Department of Water Affairs and Forestry personnel from the Port Elizabeth, East London, King Williams Town and Cradock offices and from the RDM office in Pretoria. This was also a training workshop for the Thukela RDM study participants.

Two workshops were held in 2003, one in Durban and one in Cape Town. Participants included DWAF personnel, Umgeni Water, Durban Metro, KZN Wildlife, CSIR, Ninham Shand, City of Cape Town, Western Cape Nature Conservation, Department of Environmental Affairs, Namibian Ministry of Agriculture, Water and Rural Development and UPE. From the feedback received it is obvious that participants were very appreciative of these training workshops. The DWAF RDM directorate will undertake training in the future. In the short-term when no formal training was occurring the Amazon project filled an important gap. The feedback from the RDM workshop participants as well as the training materials have been passed on to DWAF so that it can be incorporated in the design of future training workshops.

Mdloti and Mhlanga Rapid Resource Directed Measures studies

A rapid RDM study commissioned by DWAF was completed on the Mdloti Estuary in February 2002 and on the Mhlanga Estuary in April 2003. Representatives from local authorities attended the workshop as well as students and trainees from the University of Natal Durban and CSIR Environmentek. This study provided a first estimate of the freshwater requirements of the Mdloti and Mhlanga estuaries.

These reserve studies could not have been completed without the research and understanding gained from the Amazon research project "Responses of the biological communities to flow variation and mouth state in temporarily open / closed estuaries." In addition these reserve studies have improved capacity at the UND and Environmentek (Durban). Researchers now have the confidence and capacity to undertake other estuary RDM studies in the future.

Technology transfer

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MSc (pending)

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SUMMARY OF NEW KNOWLEDGE GENERATED FROM THE RESEARCH

PROJECT 1 Improving the biodiversity importance rating of SA estuaries.

Comprehensive field counts of all the birds of the Transkei coast were completed. Invertebrates were sampled in 16 warm temperate estuaries and from these data a predictive model for invertebrate community attributes was developed based on broadscale estuary characteristics. New knowledge on minimal sampling strategies for different estuarine taxa were proposed and an updated importance rating of all South African estuaries was produced.

PROJECT 2 Quantifying water quality changes that affect different taxa.

The objective of this component of the programme was not to generate new knowledge but rather to collate existing data so that information gaps could be identified. Data were mainly sourced from overseas studies indicating the lack of detailed studies on South African taxa and their water quality responses.

PROJECT 3 Responses of the biological communities to flow variation and mouth state in temporarily open / closed estuaries

Mouth condition

This research has made an important contribution to the knowledge of processes controlling the dynamics of temporarily open/closed estuaries. The results seem to support others which show that TOCEs experience a period of biological rejuvenation some time after natural breaching, followed by a period of maximal productivity shortly after the re-closure of the mouth (Whitfield 1992, Nozais *et al.* 2001). For microphytobenthos this was approximately two weeks and for zooplankton it was two-four weeks after mouth closure.

New insights on the process of mouth breaching have been gained. Observations have shown that high seepage flows through the sandbar to the sea cause erosion of the beach face and slumping of the sandbar. Wave overtopping was important in lowering the height of the berm, which promoted overflow and scour.

Recruitment

The research has shown that overtopping of the berm can result in fish recruitment but minimal invertebrate recruitment. The dominance of estuarine dependent species in the catches, almost to the exclusion of other marine species, demonstrates a remarkable ability of the small larvae to manoeuver and orientate in the surfzone for the purpose of recruitment to the estuaries. *Rhabdosargus holubi* juveniles were of a similar size, approximately 28 days post hatch. This single cohort in the catches begs the question whether adult spawning, and hence juvenile arrival at the beaches, for recruitment to estuaries might be linked to the lunar cycle in this species.

Sewage discharge

The study has highlighted the problems associated with sewage discharge to temporarily open / closed estuaries e.g. algae blooms and low oxygen concentrations. Sewage discharge also increases base flow, thus increasing the water level in the estuary causing premature mouth breaching. The Mhlanga Estuary was shown to be in an unstable state due to the frequent breaching of the mouth. The greater abundance and biomass of fish in the Mdloti Estuary compared to the Mhlanga Estuary was related to the greater water retention within the system (i.e. longer periods of mouth closure).

RECOMMENDATIONS FOR TECHNOLOGY TRANSFER OF RESULTS

PROJECT 1 Improving the biodiversity importance rating of SA estuaries.

The updated biodiversity importance ranking of all SA estuaries will be used by DWAF in future RDM studies. The importance rating of a system is an important step in the RDM process that is used to set the recommended ecological category of the estuary.

PROJECT 2 Quantifying water quality changes that affect different taxa.

The database on the CD will be available to be used in all RDM studies. In this way people will utilise the available information as well as provide further data for the improvement of the current database.

PROJECT 3 Responses of the biological communities to flow variation and mouth state in temporarily open / closed estuaries

The results from this project were used to set the ecological flow requirements of the Mdloti and Mhlanga estuaries (DWAF RDM studies). Transfer of results has thus taken place and indeed the research increased the confidence of the RDM assessments. This project has provided good baseline data for future monitoring of the Mdloti and Mhlanga estuaries. Important new knowledge was generated in this project that had direct application to management problems. This has already been implemented in the re-direction of sewage effluents away from the Mhlanga and Mdloti estuaries. The new water treatment system planned by Ethekweni Water Services (Durban Metro) will now discharge to the Mgeni Estuary. The study has highlighted the problems of sewage discharge to temporarily open / closed estuaries (i.e increased flow and unnatural breaching). In particular the eutrophication processes at Mhlanga Estuary can serve as a case study for testing responses in similarly affected estuaries.

RECOMMENDATIONS FOR FUTURE RESEARCH

PROJECT 1 Improving the biodiversity importance rating of SA estuaries.

Future studies should address the following needs:

1. Completion of the habitat area and total area estimates for all estuaries. This includes checking the existing area data in cases where there are doubts about accuracy. It would be particularly useful if the estuaries were digitized in a geographic information system (GIS).

2. Sampling of invertebrates from a lot more systems. This would improve the accuracy of the models produced in this study, and would also provide useful baseline data for future RDM assessments, especially rapid or desktop assessments.
3. An in depth study of the trade-off between sampling effort and data quality for estuarine fishes, allowing an evaluation of the Harrison data used in the index versus use of the other more comprehensive data-sets, and implications for the fish importance rating.
4. A total recount of birds of all the South African estuaries to update the counts which are mostly over 20 years old.
5. A sensitivity analysis of the weightings in the importance index. Testing of the index is needed, to investigate the effects of, for example, only retaining the biotic elements, or reducing the weighting of the zonal type rarity index.

PROJECT 2 Quantifying water quality changes that affect different taxa.

The collation of available information in one database can be used to identify gaps. Overall the study has shown that there is little ecophysiology and ecotoxicology data for most of South Africa's estuarine biota. Thus there is plenty of scope for detailed studies on individual taxa.

PROJECT 3 Responses of the biological communities to flow variation and mouth state in temporarily open / closed estuaries

This study has emphasized the need for medium / long term monitoring programmes for key estuaries. Climate change and an increase in the frequency of droughts will have a major influence on the mouth dynamics of temporarily open / closed estuaries. It is recommended that a programme on the effects of climate change on estuaries be initiated. Research into the mechanisms of mouth breaching is necessary particularly in light of the response of the mouth to slumping as a result of outflow of estuary water. Investigations of this nature should be extended to temporarily open / closed warm temperate estuaries.

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RESPONSES OF THE BIOLOGICAL COMMUNITIES TO FLOW VARIATION AND MOUTH STATE IN TWO TEMPORARILY OPEN / CLOSED KWAZULU-NATAL ESTUARIES

LIST OF ABBREVIATIONS

ANOVA:	Analysis of Variance
Chl-a:	Chlorophyll-a
CERM:	Consortium for Estuarine Research and Management
CSIR:	Council for Scientific and Industrial Research
CWAC:	Co-ordinated Water Bird Counts
DIN:	Dissolved Inorganic Nitrogen
DIP:	Dissolved Inorganic Phosphorous
DO:	Dissolved Oxygen
DW:	Dry Weight
DWAF:	Department of Water Affairs and Forestry
EMDS:	Estuarine Marine Dependent Species
FDC:	Flow Duration Curve
KZN:	KwaZulu-Natal
MAE:	Mean Annual Evaporation
MAP:	Mean Annual Precipitation
MAR:	Mean Annual Runoff
MPB:	Microphytobenthos
MSL:	Mean Sea Level
PAR:	Photosynthetically Available Radiation
RDM:	Resource Directed Measures
SD:	Standard Deviation
SL:	Standard Length
TOCE:	Temporarily Open/Closed Estuary
UPE:	University of Port Elizabeth
WLS:	Water Level Sensor
WR90:	Surface Water Resources of SA, 1990 (Midgley *et al.* 1994)
WRC:	Water Research Commission
WWTW:	Waste Water Treatment Works

Contributions to Information Requirements for the Implementation of Resource Directed Measures for Estuaries

Volume 1

(Project 1)

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REPORT TO THE WATER RESEARCH COMMISSION

BY

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ON BEHALF OF

THE CONSORTIUM FOR ESTUARINE RESEARCH AND MANAGEMENT

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1. INTRODUCTION

Jane Turpie

1.1 Background and rationale

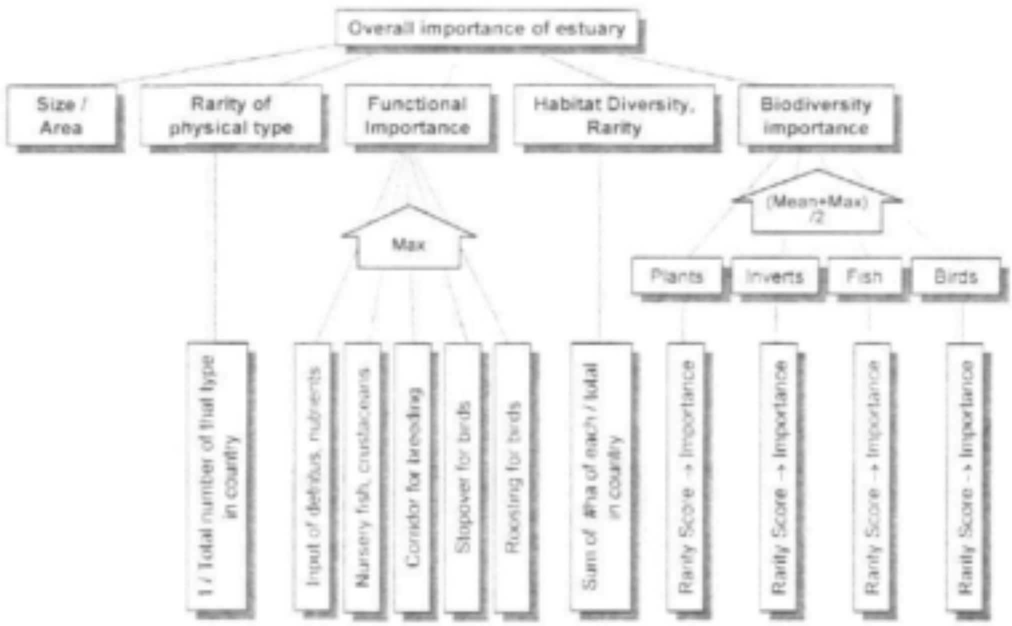
Estuaries represent the most anthropogenically degraded habitat type on earth (Edgar *et al.* 2000). In South Africa, while many estuaries are still in a relatively good condition (Turpie 2003), numerous direct threats such as the development of marinas and resorts, land reclamation projects and increasing human disturbance and exploitation are jeopardizing the health and functioning of estuaries in the country (Schlacher & Woolridge 1996, Turpie *et al.* 2002, Turpie 2003). In addition, catchment degradation and the reduction or alteration of freshwater flows into estuaries constitutes a significant threat to the functioning of these ecosystems. Sound estuary management and meeting the ecological requirements for freshwater inputs will thus be the two main factors influencing the future health and productivity of estuarine habitats (Turpie *et al.* 2002). While both aspects are vitally important, this study is concerned with the determination of freshwater inputs into estuaries.

The new National Water Act (36) 1998 makes provision for an environmental reserve (a minimum input of water quantity and quality) which ensures the continued ecological functioning of aquatic ecosystems. However, there is a range of possibilities in that freshwater flows can be controlled to maintain aquatic ecosystems in various states ranging from a near-pristine state (e.g. due to very little abstraction of water) to a satisfactorily-functioning, but altered state (Turpie *et al.* 2002). The proportion of the natural flow which is reserved for the environment will be determined by a new set of methods called "Resource Directed Measures" (RDM; = measures directed at maintaining the aquatic resource) and will vary depending on ecological, social and economic goals (Adams *et al.* 1999). The decision process involves assigning a "management class" to each water resource, with a high class usually requiring a higher proportion of the water supply allocated to the environment. For estuaries, the ecological goal (water requirement from a solely ecological perspective) is determined on the basis of ecosystem health and importance for biodiversity conservation.

The health of an estuary is determined using a set methodology which is applied when an estuary is selected for an RDM study. The importance of an estuary is a relative measure, however, and cannot be determined in isolation. Thus the RDM procedure relies on a predetermined importance score for each estuary in the country, which in turn relies on an understanding of estuarine biodiversity in all South African estuaries. When the RDM method was initially developed (*ca.* 2000), the importance score had to be devised relatively rapidly, based on available data (Turpie *et al.* 2002). Box 1 summarises the way in which the importance scores were derived; details of the method are given in Turpie *et al* (2002).

Box 1. A summary of the method used for determining an estuary's importance score

An estuary's importance was defined as its importance in maintaining ecological diversity and functioning on local and wider scales. Estuarine attributes included in the index and their weightings were chosen in a workshop involving a wide range of estuarine scientists. The composition of the score is illustrated by the following value tree:



Apart from functional importance, which is based on scores out of 100, the remaining scores are converted to deciles, so that estuaries scoring in the top 10% are given a score of 100, in the next 10% are given a score of 90, and so on. This is because of the skewness of the area data and rarity scores. Rarity scores are based on the Species Rarity Index as follows:

$SRI = 100x\sum_{i=1}^{n} r_i$, where r_i = the rarity score of the *i*th species, and

$r_i = \frac{q_i}{Qi}$ based on abundance data or $r_i = \frac{1}{Ni}$ based on presence-absence data,

where q_i = number (or area) in estuary and Q_i = total number (or area) in all SA estuaries or coast, and Ni is the number of estuaries in which the species occurs in South Africa. Whereas functional importance is determined at an RDM workshop, the other components of the index have been computed for all South African estuaries (Turpie *et al.* 2000).

Components of the biodiversity importance score are weighted equally. The Importance index is based on the following weighting:

Attributes	Weighting if computed without last attribute	Final Weighting
Size	40	15
Zonal type rarity	10	10
Habitat diversity	25	25
Biodiversity importance	25	25
Functional importance		25

1.2 Shortcomings of the existing importance rating

The available data upon which the importance scores were based were patchy and of varying quality. Thus, in the ensuing years during which the methodology has been tested on a handful of estuaries, there has been ongoing debate on how the importance rating might be improved.

The data used by Turpie *et al* (2002) are briefly summarised below, together with some of their shortcomings that have undermined the accuracy of the importance rating scores:

1. The estuary list: The list of estuaries included in the study is based on the strictest published list of functional estuaries (Whitfield 2000) but could be expanded to include others such as Verlorenvlei or even Langebaan Lagoon;
2. Area data come from several sources, and have not been measured in a standard way for all the estuaries;
3. Botanical data: These are relatively up-to-date and complete, although there are a few data gaps.
4. Invertebrate data: No empirical data were used, and due to the lack of a database comparable to other taxa, the invertebrate index had to be based on distribution ranges of estuarine invertebrates (i.e. assuming that a species is present if the estuary is within its range).
5. Fish data: A once-off sampling of most South African estuaries, undertaken in about 1990, was used. Apart from a few gaps in this data set, these data are mainly criticised in that they are based on a very limited number of samples in each estuary. A single sampling may not adequately reflect an estuary's ichthyofauna;
6. Bird data: The bird count data used were from a set of once-off summer counts of the estuaries of most of the entire coastline apart from the Transkei-Ciskei coasts. These data are more than 20 years out of date, only cover about two-thirds of the estuaries, and a single count may not adequately reflect an estuary's avifauna.

Thus there are some significant gaps in the data used to generate the importance rating. Where no data were available, an estuary was assumed to score in the lowest decile for that taxon. Although this is probably true in many cases, since it is often the very small estuaries that have not been sampled, this generalisation may not always hold true. Much information is required to fill data gaps in this database, in order to come up with a more confident or robust rating of estuarine importance. Because the botanical data are relatively up-to-date and complete, this study concentrates on the three faunal components, invertebrates, fish and birds, with special emphasis on invertebrates.

1.3 Aims of this study

The aims of this study were as follows:

1. To improve the existing database through collation of published and unpublished data on invertebrates, fish and birds from individual estuaries;
2. To fill some of the information gaps by doing field work (e.g. the total lack of bird count data for the Wild Coast region); and
3. To improve the estimates made for remaining information gaps using predictive models, based on analysis of existing data and data collected in this study.
4. To update the importance rating of all South African estuaries on the basis of improved information and understanding.

1.4 Study approach and limitations

It was considered probable that some of the gaps in information could be filled with existing information that had not previously been collated, such as data collected for environmental impact studies or other grey literature. Thus the first step of the study involved an intensive literature search and contacting key practitioners in the field to find out about the availability of data. Where possible, data were obtained and collated in a database.

For the remaining gaps, new data needed to be generated. Some of these could feasibly be filled by straightforward field data collection. Thus it was decided that the simplest way of generating bird data for the estuaries of the Transkei – Ciskei coasts, the biggest data gap for birds, was to conduct a count of this area. The coast was traversed on foot by three counters in January – February 2002. Invertebrates were also sampled in some of the estuaries during this study. Some additional counts were made during a subsequent visit to the same area in January 2004. Unfortunately, budget limitations precluded the sampling of fishes, for which data are missing from a number of Transkei estuaries.

There are so few invertebrate data available that field sampling of all the remaining (over 200) estuaries for invertebrate fauna would not be feasible within a study such as this. Thus this study attempted to seek rapid methods of assessment that would yield more robust results, based on modelling of field data. Because so few field data are available, particularly for intertidal invertebrate fauna, it was necessary to first develop a more thorough understanding of the invertebrate fauna of selected estuaries through a field study. Thus intertidal invertebrates were sampled intensively in 16 estuaries. The number of estuaries was limited due to budgetary constraints (<R12 000 per estuary, including analysis), and thus it was decided to confine the field study to permanently or temporarily open estuaries of the warm temperate zone (between Cape Point and roughly the Mbashe estuary).

Following this, all available field data on invertebrates (benthic intertidal, benthic subtidal and planktonic) were analysed in an attempt to produce predictive relationships that could generate scores for estuaries for which no data were available. These relationships had to be based on estuary characteristics for which data were readily available for all estuaries. Although predictive relationships are generated for the both warm temperate and subtropical estuaries, it should be borne in mind that the data quality is biased towards the warm temperate zone.

The different sampling efforts for different taxa have yielded all sorts of data which vary in their potential for inclusion in the importance rating of estuaries. Thus before updating the current index, the implications of using different types of data, and of sampling at different intensities, was explored. This gave rise to the rationale used in the updating of the importance scores, which are reported in the final section.

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2. EXISTING DATA ON AREA, PLANTS, INVERTEBRATES, FISH AND BIRDS OF SOUTH AFRICAN ESTUARIES

Jane Turpie

2.1 Introduction

As a prerequisite to updating the importance rating of estuaries, it was necessary to review the existing data required for this exercise, determine its availability, and collate the data for further analysis where appropriate. The study thus set out to do the following:

- Source all species lists and quantitative information on invertebrates, fish and birds for South African estuaries, from the published literature, student projects, EIA studies, etc.;
- Devise a way of recording the information so that it can be easily updated and summarised for each estuary;
- Convert different types of sampling data into common units where necessary; and
- Update the summary database.

2.2 Area data

Although not specifically an element of this study, the area of an estuary is an important component of the importance index, and was thus considered worthy of a brief mention in terms of data availability. Area data were obtained from three main sources: Colloty's (2001) database on habitat areas (see below), Cowan's (1995) collation of data on South African wetlands, and CERM's (1996) database produced for an estuary ranking exercise. CERM's database was originally used as the primary data source (Table 2.1). However, in this case, the areas of the estuaries probably came from numerous sources, and using various methods to define the upstream, seaward and lateral extents of the estuaries. Colloty's (2001) database is the only data set which is consistent in its definition of estuary boundaries, and was thus subsequently taken as the primary source. Nevertheless, while the overall reliability of the area measurements is considered to be much improved, there are still some estuaries where the accuracy of these measurements may be debatable, and a few estuaries for which alternative sources had to be used or no data were available. This would probably merit some further detailed research. However, area data have not been further updated in this study.

2.3 Plant data

Similarly, plant and habitat data are not updated in this study, due to the database being relatively recent and complete. Colloty's (2001) database pulls together information gathered for the Botanical Importance Rating of South African estuaries (e.g. Coetzee *et al.* 1997, Colloty *et al.* 1998, Colloty *et al.* 2001) and updates the data in Colloty (2000). This exercise entailed quantifying habitat areas from recent and past (*ca* 1960) aerial photographs of 230 (90%) of the 255 estuaries considered in the importance rating. It is interesting to note, though that recent data were available for only 157 estuaries, whereas historic data were available for 186 estuaries. Where both were available, the most recent data was used. Colloty's (2001) database includes species lists for 228 estuaries (89%). The variation in sampling effort and completeness of these lists is unknown, however.

Table 2.1. Available information on the size, habitat areas and plant species of South African estuaries. Estuaries are classified as River mouths (R), Permanently open (O), Temporarily open/closed (C), Estuarine Bay (B) or Estuarine Lake (L). Habitat cover data from Colloty 2001 are either for present cover, past cover or both. Plant species data are as listed in Colloty 2001. Estuaries are listed from west to east.

No	ESTUARY	Type	Size (ha)	Hab cover	Plant spp
1	Orange (Gariep)	R	974.52	both	Y
2	Olifants	O	701.69	pres	Y
3	Berg (Groot)	O	3615	pres	Y
4	Rietvlei/Diep	C	515		Y
5	Houtbaai	R		past	Y
6	Wildevoëlvlei	C	75.79	both	Y
7	Bokramspruit	C			Y
8	Schuster	C			
9	Krom	C			Y
10	Silvermine	C	6.52	both	Y
11	Sand	C	155.48	pres	Y
12	Eerste	C	10.2	pres	Y
13	Lourens	C	7.09	pres	Y
14	Sir Lowry's Pass	C	2.95	both	Y
15	Steenbras	O	1.88	both	
16	Rooiels	C	10.84	both	Y
17	Buffels (Oos)	C	17.28	both	Y
18	Palmiet	O	33	both	Y
19	Bot/Kleinmond	L	1698.4	past	Y
20	Onrus	C	41.13	pres	Y
21	Klein	L	2958.9		Y
22	Uilskraals	C	104.7	both	Y
23	Ratel	C	10		Y
24	Heuningnes	O	172.51	both	Y
25	Klipdrifsfontein	C			
26	Breë	O	455.28	pres	Y
27	Duiwenhoks	O	203.07	both	Y
28	Goukou	O	154.76	both	Y
29	Gourits	O	112.58	both	Y
30	Blinde	C			Y
31	Hartenbos	C	40.59	both	Y
32	Klein Brak	C	96		Y
33	Groot Brak	C	113.92	pres	Y
34	Maalgate	C	13.5		Y
35	Gwaing	C			Y
36	Kaaimans	O	8		Y
37	Wilderness	L		pres	Y
38	Swartvlei	L	1076.6		Y
39	Goukamma	C	270		Y
40	Knysna	Bay	3594	both	Y
41	Noetsie	C	8		Y
42	Piesang	C	92.24	pres	Y
43	Keurbooms	O	295.17	both	Y
44	Matjies/Bitou	C			
45	Sout (Oos)	O	52.22	pres	Y
46	Groot (Wes)	C	39.28	pres	Y
47	Bloukrans	R			Y
48	Lottering	R	17		Y
49	Elandsbos	R	6		Y
50	Storms	R		pres	Y

No	ESTUARY	Type	Size (ha)	Hab cover	Plant spp
52	Groot (Oos)	R			Y
53	Tsitsikamma	C		pres	Y
54	Klipdrif	C			Y
55	Slang	C			
56	Kromme	O	240.34	both	Y
57	Seekoei	C	132.22	both	Y
58	Kabeljous	C	117.94	both	Y
59	Gamtoos	O	467.03	both	Y
60	Van Stadens	C	28	pres	Y
61	Maitland	C	0.2	pres	Y
62	Swartkops	O	499	both	Y
63	Coega (Ngcura)	C	10.14	pres	Y
64	Sundays	O	173.37	pres	Y
65	Boknes	C	27	past	Y
66	Bushmans	O	213	past	Y
67	Kariega	O	198	past	Y
68	Kasuka	C	38	past	Y
69	Kowie	O	118.63	pres	Y
70	Rufane	C			Y
71	Riet	C	73.06	past	Y
72	Kleinemond Wes	C	80	past	Y
73	Kleinemond Oos	C	35	past	Y
74	Klein Palmiet	C			
75	Great Fish	O	365.68	both	Y
76	Old woman's	C	25.12	both	Y
77	Mpekweni	C	141.41	both	Y
78	Mtati	C	124.2	both	Y
79	Mgwalana	C	123.62	both	Y
80	Bira	C	97.49	both	Y
81	Gqutywa	C	51.64	both	Y
82	Blue Krans	C	2.54	both	Y
83	Mtana	C	15.69	both	Y
84	Keiskamma	O	493.84	both	Y
85	Ngqinisa	C	12.67	both	Y
86	Kiwane	C	18.8	both	Y
87	Tyolomnqa	C	107.44	both	Y
88	Shelbertsstroom	C			
89	Lilyvale	C	2.3	pres	
90	Ross' Creek	C			
91	Ncera	C	28.4	pres	
92	Mlele	C	3.6	pres	
93	Mcantsi	C	9	pres	
94	Gxulu	C	48.5	pres	Y
95	Goda	C	17.2	pres	Y
96	Hlozi	C	0.7	pres	
97	Hickman's	C	4.3	pres	Y
98	Buffalo	O	98	pres	Y
99	Blind	C	0.5	pres	Y
100	Hlaze	C	1.5	pres	Y
101	Nahoon	O	57.7	pres	Y
102	Qinira	C	72.13	pres	Y
103	Gqunube	O	53.4	pres	Y
104	Kwelera	O	50.1	pres	Y
105	Bulura	C	35.5	pres	Y
106	Cunge	C	0.5	pres	
107	Cintsa	C	29.3	pres	Y
108	Cefane	C	82.7	pres	
109	Kwenxura	C	29.1	pres	Y

No	ESTUARY	Type	Size (ha)	Hab cover	Plant spp
111	Haga-haga	C	3.4	pres	Y
112	Mtendwe	C	11.23	past	Y
113	Quko	C	36.18	pres	Y
114	Morgan	C	24	pres	
115	Cwili	C	1.2	pres	
116	Great Kei	O	222.4	both	Y
117	Gxara	C	23.9	both	Y
118	Ngogwane	C	9.12	both	Y
119	Qolora	C	22.9	both	Y
120	Ncizele	C	6.635	both	Y
121	Kobonqaba	O	26.4	both	Y
122	Nxaxo/Ngqusi	O	159.48	both	Y
123	Cebe	C	16.53	both	Y
124	Gqunqe	C	17.94	both	Y
125	Zalu	C	12.36	both	
126	Ngqwara	C	19.36	both	Y
127	Sihlontlweni/Gcini	C	11.01	both	Y
128	Qora	O	89.63	both	Y
129	Jujura	C	4.77	both	Y
130	Ngadla	C	13.884	both	Y
131	Shixini	O	22.1	both	Y
132	Nqabara	O	109.66	both	Y
133	Ngoma/Kobule	C	10.11	both	Y
134	Mendu	C	23.83	both	Y
135	Mbashe	O	131.95	both	Y
136	Ku-Mpenzu	C	13.38	both	Y
137	Ku-Bhula/Mbhan.	C	7.6	both	Y
138	Ntlonyane	C	41.34	both	Y
139	Nkanya	C	15.47	both	Y
140	Xora	O	150.58	both	Y
141	Bulungula	C	18.4	both	Y
142	Ku-amanzimuz.	C	3.65	both	Y
143	Mncwasa	C	19.216	both	Y
144	Mpako	C	13.51	both	Y
145	Nenga	C	10.01	both	Y
146	Mapuzi	C	15.9	both	Y
147	Mtata	O	168.79	both	Y
148	Mdumbi	O	76.07	both	Y
149	Lwandilana	C	9.69	both	Y
150	Lwandile	C	22.2	both	Y
151	Mtakatye	O	116.81	both	Y
152	Hluleka/Majusini	C	14.9	both	Y
153	Mnenu	C	90.52	both	Y
154	Mtonga	C	32.2	both	Y
155	Mpande	C	15.04	both	Y
156	Sinangwana	C	13.2	both	Y
157	Mngazana	O	224.85	both	Y
158	Mngazi	C	17.1	both	Y
159	Bululo	C	12.62	both	Y
160	Mtambane	C	10.94	both	Y
161	Mzimvubu	R	150.99	both	Y
162	Ntlupeni	C	4.37	both	Y
163	Nkodusweni	C	32.6	both	Y
164	Mntafufu	O	24.07	both	Y
165	Mzintlava	O	23.06	both	Y
166	Mzimpunzi	C	5.08	both	Y
168	Mkozi	C	4.01	both	Y
169	Myekane	C	1.92	both	Y

No	ESTUARY	Type	Size (ha)	Hab cover	Plant spp
170	Lupatana	C	3.55	both	Y
171	Mkweni	C	7	both	Y
172	Msikaba	O	15.13	both	Y
173	Mgwegwe	C	8.79	both	Y
174	Mgwetyana	C	3.28	both	Y
175	Mtentu	O	52.93	both	Y
176	Sikombe	C	11.48	both	Y
177	Kwanyana	C	7.13	both	Y
178	Mnyameni	C	27.92	both	Y
179	Mpahlanyana	C	3.85	both	Y
180	Mpahlane	C	3.92	both	Y
181	Mzamba	O	70.94	both	Y
182	Mtentwana	C	11.43	both	Y
183	Mtamvuna	C	63.53	both	Y
184	Zolwane	C	0.5	past	Y
185	Sandlundlu	C	4	past	Y
186	Ku-boboyi	C	1.1	past	Y
187	Tongazi	C	0.8	past	Y
188	Kandandhlovu	C	1.8	past	Y
189	Mpenjati	C	11.6	past	Y
190	Umhlangankulu	C	9.7	past	Y
191	Kaba	C	2.4	past	Y
192	Mbizana	C	12.4	past	Y
193	Mvutshini	C	0.9	past	
194	Bilanhlolo	C	2.6	past	Y
195	Uvuzana	C	0.6	past	
196	Kongweni	C	1.4	past	Y
197	Vungu	C	1.1	past	Y
198	Mhlangeni	C	3.6	past	
199	Zotsha	C	7.3	past	Y
200	Boboyi	C	1.3	past	Y
201	Mbango	C	0.9	past	
202	Mzimkulu	O	74	past	Y
203	Mtentweni	C	8	past	Y
204	Mhlangamkulu	C	3.9	past	Y
205	Damba	C	1.7	past	Y
206	Koshwana	C	1.2	past	Y
207	Intshambili	C	1.7	past	Y
208	Mzumbe	C	15.8	past	Y
209	Mhlabatshane	C	2.3	past	Y
210	Mhlungwa	C	3.1	past	Y
211	Mfazazana	C	2.1	past	Y

No	ESTUARY	Type	Size (ha)	Hab cover	Plant spp
214	Mtwalume	C	24.8	past	Y
215	Mvuzi	C	0.8	past	
216	Fafa	C	29	past	Y
217	Mdesingane	C	0.4	past	
218	Sezela	C	12	past	Y
219	Mkumbane	C	0.3	past	Y
220	Mzinto	C	7	past	Y
221	Mzimayi	C	1	past	Y
222	Mpambanyoni	C	2.3	past	Y
223	Mahlongwa	C	5.9	past	Y
224	Mahlongwana	C	6.8	past	Y
225	Mkomazi	O	77.9	both	Y
226	Ngane	C	1.4	past	Y
227	Umgababa	C	17.6	past	Y
228	Msimbazi	C	13.2	past	Y
229	Lovu	C	10.5	past	Y
230	Little Manzimtoti	C	1.5	past	Y
231	Manzimtoti	C	6.7	past	Y
232	Mbokodweni	C	7.2	past	Y
233	Sipingo	O	6.8	past	Y
234	Durban Bay	B		past	Y
235	Mgeni	C	48	past	Y
236	Mhlanga	C	100.1	both	Y
237	Mdloti	C	58.1	both	Y
238	Tongati	C	37.3	both	
239	Mhlali	C	21	past	Y
240	Seteni	C	1.1	past	Y
241	Mvoti	R	18.4	past	Y
242	Mdlotane	C	25.42	both	Y
243	Nonoti	C	18	past	Y
244	Zinkwasi	C	71.16	both	Y
245	Tugela/Thukela	R	55	past	Y
246	Matigulu/Nyoni	O	192	past	Y
247	Siyaya	C	7.69	both	Y
248	Mlalazi	O	202.4	both	Y
249	Mhlathuze	B	1691	both	Y
250	Richard's Bay	B	1800		
251	Nhlabane	L	14.4	both	Y
252	Mfolozi	R	180	past	Y
253	St Lucia	L	38290	both	Y
254	Mgobezeleni	L	1.3	past	Y
255	Kosi	L	3500	past	Y

2.4 Invertebrate data

There has been a considerable amount of research on invertebrates in South African estuaries. This information has never been collected in a systematic fashion or collated in any way, however, apart from the presentation of information on the estuaries of Natal by Begg (1978), and data summaries in the Estuaries of the Cape series (Heydorn & Tinley 1980). However, neither compilation provides comprehensive data on estuarine invertebrates. Begg (1978) provides data mainly on pelagic invertebrates such as swimming prawns and crabs, and Heydorn & Tinley (1980) provide lists of species recorded, but their comprehensiveness is variable.

Emmanuel *et al.* (1992) and Awad *et al.* (2002) compiled detailed information on the distribution of invertebrates around the South African coast. The existing importance rating used the latter data to develop a data set of the distributions of estuarine species. This was then used to devise lists of potentially present species in all South African estuaries. However, it was recognised that this was to be an interim measure until a better indicator of estuary importance for invertebrates could be devised.

Estuarine invertebrates are a complex group that can be divided into several sub-groupings based on general habitat, behaviour and size. Few, if any, studies attempt to quantify all types of invertebrates in an estuary, with most of the literature dealing with the biology of selected species. Furthermore, studies that do describe aspects of invertebrate communities are often limited to covering a certain size range (determined by sampling mesh size), and to a certain ecological grouping. Available data for each grouping are described below.

2.4.1 Zooplankton

Zooplankton studies can be distinguished on the basis of the size of organisms described. Microzooplankton comprises pelagic invertebrates smaller than 200µm. There are very few data on these e.g. Jerling (1993) for the Sundays estuary; Wooldridge (1979) (on nauplii larvae only) in the Swartkops estuary.

Most work on zooplankton concentrates on the mesozooplankton. Many studies of these have been restricted to selected groups such as copepod and mysid species (e.g. Wooldridge 1979, Jerling & Wooldridge 1995). However, several studies describing estuarine zooplankton communities have been carried out (e.g. Wooldridge 1976, 1977, Coetzee 1983, 1985, Davies 1987, Deysel 2001), although much of this work has not yet been written up or published (e.g. Wooldridge unpublished data for 12 Cape estuaries). In all, zooplankton data could be located for a total of 23 estuaries (9%).

2.4.2 Nektonic invertebrates

This group comprises the larger invertebrates which are capable of active swimming and characteristically migrate between estuarine nursery habitats and offshore areas (Forbes 1999). This group includes the penaeid prawns, the portunid crab *Scylla serrata* and the palaemonid shrimps (Forbes 1999). There has been extensive work on the biology of these species in KwaZulu-Natal, but comparatively little elsewhere. Although this group is more characteristic of tropical estuaries, there are species that extend into temperate areas. Begg (1984a,b) lists the prawn species captured in trawls for a large number of KwaZulu-Natal estuaries (in addition to the fish and crab species).

2.4.3 Benthic meiofauna

Very little work has been carried out to describe this group, e.g. Dye & Furstenberg's (1978) description of meiofauna in the Swartkops estuary and Dye (1983). Meiofauna biomass has been estimated from carbon biomass measurements, e.g. for the Kromme, Swartkops and Sundays estuaries (Charler *et al.* 1998).

2.4.4 Benthic macrofauna

Much of the work carried out on estuarine invertebrates is on the macrobenthos, with numerous surveys having been carried out both in KwaZulu-Natal and Cape estuaries (e.g. Boltt 1975, Blaber *et al.* 1983, Hay 1985a, Hodgson 1987, Hanekom *et al.* 1988, Whitfield 1989; see Table 2.2). Teske & Wooldridge (2001), based on Teske (2000), describes the macrobenthos of 12 Eastern Cape estuaries, although sampling excluded the intertidal area. In addition to published data, unpublished assessments include Sogayisa's work in 10 Eastern Cape estuaries (towards an MSc at Fort Hare) and this study (16 Cape estuaries). Whereas Sogayisa sampled the subtidal benthos only, this study concentrated only on the intertidal benthos, with a view to complementing the work of Teske and others. Other unpublished data includes the work of Trevor Harrison, who took about 9 core samples in each of the KwaZulu-Natal estuaries (samples housed at the University of Zululand, but not analysed), and the 9 – 12 cores taken by Barry Clark in five Transkei estuaries (results included in this study). Recent research projects have involved comprehensive sampling of invertebrates at three Transkei estuaries (Nxaxo, Mngazana and Mngazi – Wooldridge, pers. comm.) and detailed work is underway on the Berg River estuary by Tris Wooldridge's group (subtidal and plankton) and Barry Clark (intertidal), but the data are not yet available. Estuary freshwater requirement studies have resulted in data collection for the Palmiet, Breede and Thukela estuaries, and will shortly yield data for the Kromme, Seekoei and Olifants estuaries. The estuaries for which invertebrate data are available are summarised in Table 2.2.

Usually sampled with grabs, benthic macrofauna studies usually describe fauna that are extracted with a 0.5mm sieve, although coarser sieves have also been used (e.g. 1mm - Pemberton 2001). There has been less emphasis on the intertidal component of the benthic macrofauna than the subtidal component, however, especially in Cape estuaries. Another point of interest is that in KwaZulu-Natal and some Cape estuaries (e.g. Nahoon – Bursey & Wooldridge 2002), the intertidal fauna has largely been sampled using grabs at high tide, whereas in the Cape, the sampling technique has been using cores taken at low tide (e.g. Kalejta & Hockey 1991, this study).

Due to the need for a more holistic understanding of estuarine communities and functioning, for example for the determination of freshwater requirements of estuaries, there is an increasing trend for studies to be more comprehensive. Invertebrate studies are increasing including all aspects, including subtidal and intertidal macrobenthos (sieved to 0.5mm), plankton, and more recently, hyperbenthos (e.g. Wooldridge 2001). The latter are collected using sleds.

Macrobenthos data are available for at least 51 South African estuaries (20%) (Table 2.2). The macrobenthos has been described for some 46 Cape estuaries (Northern, Western and Eastern Cape), or 25%, whereas data are known from only 7% of KwaZulu-Natal estuaries.

Table 2.2. Summary of the degree of available information on invertebrates in South African estuaries. SL = species lists only; Quant = quantitative data; P = published, G = grey literature, Pvt = exists in private collections; CWAC = quantitative Co-ordinated Waterbird Count data, available for a fee from ADU, University of Cape Town. Note that only estuaries for which data exist are listed (see Table 2.1 for complete estuary list) (note: this may exclude some recent work in KZN)

No	ESTUARY	Type	Size (ha)	Intertidal macrobenthos	Subtidal macrobenthos	Plankton
1	Orange (Gariep)	R	974.52		Forthcoming	
2	Olifants	O	701.69		Forthcoming	
3	Berg (Groot)	O	3615	Kalejta & Hockey 1991		
16	Rooiels	C	10.84	This study		
18	Palmiet	O	33	This study		
19	Bot/Kleinmond	L	1698.4		DeDecker & Bally 1985; DeDecker 1987	Coetzee 1983, 1985
24	Heuningnes	O	172.51	This study		
26	Breë	O	455.28	Wooldridge 2001; Pemberton 2001; This study	Wooldridge 2001 (incl hyperbenthos)	Wooldridge 2001
32	Klein Brak	C	96	This study		
33	Groot Brak	C	113.92		Monitoring programme	Monitoring programme
36	Kaaimans	O	8	This study		
38	Swartvlei	L	1076.63		Davies 1982	
40	Knysna	Bay	3594			Davies 1987
56	Kromme	O	240.34	Charler *et al.* 1998, Baird *et al.* 1981	Teske 2000, Teske & Wooldridge 2001	Wooldridge unpubl; Estuaries of the Cape 1988; Charler *et al.* 1998
57	Seekoei	C	132.22		Forthcoming	
58	Kabeljous	C	117.94	This study	Teske 2000, Teske & Wooldridge 2001	Schlacher & Wooldridge 1995
59	Gamtoos	O	467.03	This study	Shlacher & Wooldridge 1996, Callahan 2001	Estuaries of the Cape; Callahan 2001
60	Van Stadens	C	28		Teske 2000, Teske & Wooldridge 2001	Wooldridge unpubl 1998
62	Swartkops	O	499	Hanekom *et al.* 1988; Charler *et al.* 1998, This study	MacLachlan & Grindley 1974; Teske 2000, Teske & Wooldridge 2001	Glen 1980; Charler *et al.* 1998
64	Sundays	O	173.37	Forbes 1994, Charler *et al.* 1998, This study	Teske 2000, Teske & Wooldridge 2001	Wooldridge & Bailey 1982; Jerling & Wooldridge 1995; Charler *et al.* 1998
66	Bushmans	O	213	This study		
67	Kariega	O	198	Hodgson 1987, This study	Teske 2000, Teske & Wooldridge 2001	Wooldridge unpubl 1998
69	Kowie	O	118.63		Estuaries of the Cape	Estuaries of the Cape 1981
72	Kleinemond W	C	80		Hill 1965	
73	Kleinemond E	C	35	Forbes, T.	Teske 2000, Teske & Wooldridge 2001	Wooldridge unpub. 1998
75	Great Fish	O	365.68	This study	Teske 2000, Teske & Wooldridge 2001	Wooldridge unpubl 1998
76	Old woman's	C	25.12		Teske 2000, Teske & Wooldridge 2001	Wooldridge unpubl 1998
77	Mpekweni	C	141.41		Teske 2000, Teske & Wooldridge 2001	Wooldridge unpubl 1998

No	ESTUARY	Type	Size (ha)	Intertidal macrobenthos	Subtidal macrobenthos	Plankton
78	Mtati	C	124.2		Teske 2000, Teske & Wooldridge 2001	Wooldridge unpubl 1998
79	Mgwalana	C	123.62	This study		Wooldridge unp. 1998
81	Gqutywa	C	51.64		Teske 2000, Teske & Wooldridge 2001	Wooldridge unpubl 1998
84	Keiskamma	O	493.84	This study	Teske 2000, Teske & Wooldridge 2001	Wooldridge unpubl 1998
86	Kiwane	C	18.8		Sogayisa 2000	
87	Tyolomnqa	C	107.44	This study		
89	Lilyvale	C	2.3		Sogayisa 2000	
94	Gxulu	C	48.5		Sogayisa 2000	
95	Goda	C	17.2		Sogayisa 2000	
96	Hlozi	C	0.7		Sogayisa 2000	
97	Hickman's	C	4.3		Sogayisa 2000	
101	Nahoon	O	57.7	Bursey 1998; Bursey & Wooldridge 2002	Bursey 1998, Bursey & Wooldridge 2002	
107	Cintsa	C	29.3		Sogayisa 2000	
108	Cefane	C	82.7		Sogayisa 2000	
110	Nyara	C	17.1		Sogayisa 2000	Perissinotto *et al.* 2000, Walker *et al.* 2001.
122	Nxaxo/Ngqusi	O	159.48	Clark unpubl		Deysel 2001
126	Ngqwara	C	19.36	Clark unpubl		
127	Sihlontlweni/Gcini	C	11.01	Clark unpubl		
128	Qora	O	89.63	Clark unpubl		
135	Mbashe	O	131.95	Clark unpubl		
157	Mngazana	O	224.85	Branch & Grindley 1979	Forthcoming	Wooldridge 1977
158	Mngazi	C	17.1		Forthcoming	
172	Msikaba	O	15.13			Wooldridge 1976
189	Mpenjati					Kibirige 2002
227	Umgababa					Grindley 1981
236	Mhlanga				Whitfield 1980	Whitfield 1980a,b
237	Mdloti	C	58.1		This study Vol III	Blaber *et al.* 1984
238	Tongati				Blaber *et al.* 1984	Blaber *et al.* 1984
245	Tugela/Thukela	R	55		Recent RDM study	
247	Siyaya	C	7.69		Cyrus unpubl data	
249	Mhlathuze	Bay	1691		Mackay & Cyrus 1998/9	Connell *et al.* 1981, Jerling 1998/9, van der Elst *et al.* 19999
251	Nhlabane				Forbes & Demetriades 2000, 2002; Vivier *et al.* 1998	
253	St Lucia	L	38290		Boltt 1975, Blaber *et al.* 1983, Hay 1985; Cyrus 1988; Owen & Forbes 1997	

2.5 Fish data

As with invertebrates, research on fish has been concentrated in a few areas, notably in estuaries close to academic research institutions. There has, however, been one study of estuarine fish which was country wide. As part of the data collection for an estuarine health index, Harrison sampled fishes in 215 of the South African estuaries considered in this study (84%). Although based on only a few samples per estuary, the data set provides a standardised set of once-off samples which are comparable from estuary to estuary. These data are mostly from the 1990s, but because of small sampling effort, do not pick up rare species. The raw data (Harrison, unpubl. data) are in the form of numbers of each species caught in each estuary.

Other studies have provided far more comprehensive assessments of the ichthyofauna of individual estuaries or groups of estuaries (e.g. Marais & Baird 1980, Marais 1982a,b, 1983a,b, 1996, Plumstead *et al.* 1985, 1989a, 1991, Bennet *et al.* 1985, Whitfield 1980a,b,1988, Cloete 1990, Whitfield *et al.* 1994, Russel 1996, TerMorshuizen *et al.* 1996, 1997, Cowley 1998, Weerts & Cyrus 1998/9, Lamberth 2001). Many studies have concentrated on the larval component, or ichthyoplankton (e.g. Melville-Smith & Baird 1980, Melville-Smith 1981, Beckley 1984, Strydom 1995, Harris & Cyrus 1995, 1997, 1999). Although none of the above studies predate 1980, Day *et al.* (1981) give fish species recorded in 24 estuaries.

More comprehensive data have recently been collected for over 30 Cape estuaries by Steve Lamberth (13 estuaries), Paul Cowley (4 estuaries), Angus Paterson (1 estuary), Paul Voerwek (11 estuaries) and Alan Whitfield and students. In addition, there have been recent fish surveys of several KwaZulu-Natal estuaries (Cyrus, pers. comm.) These studies include comprehensive once-off studies (e.g. sampling every kilometre up an estuary), and comprehensive studies that are repeated in different seasons and/or annually. One of the longest-term studies is of the fishes of the Kowie estuary (over 8 years of monthly data). While some of the data are published in summary form (e.g. Voerwek 2001), many (if not most) of these data only exist in raw form at present (not even in digital form), and as part of ongoing research projects, are yet available for public use.

2.6 Bird data:

There is a set of once-off summer counts for 178 estuaries which took place in the summers of 1979/80 and 1980/81. The entire set of counts is in a spreadsheet printout (Underhill & Cooper 1984), and parts have been published in Ryan & Cooper (1985), Ryan *et al.* (1986) and Ryan *et al.* (1988). This counting effort included counts along the entire coast, which allowed estimates to be made of the total coastal population of each species. Since about 1993, monitoring of bird numbers by volunteer counters has been carried out on 23 estuaries under the Co-ordinated Waterbird Counts project, based at the Avian Demography Unit, University of Cape Town. These comprise annual summer and winter counts. The actual count data are only available for a substantial fee, but mean, maximum and minimum numbers of each species recorded during 1993 – 7 are published in Harrison *et al.* (1997). These data have been collated in an electronic database. In addition, count data for several estuaries have been recorded in a number of grey literature reports (e.g. for Environmental Impact Assessments) and published papers (Table 2.2). Additional count data were produced for the Transkei estuaries during this study (see Chapter 3). Other bird count data (e.g. for KwaZulu-Natal estuaries) exist but have not been published or released for public use. Existing data sources for estuarine birds are summarised in Table 2.2. An electronic database was compiled summarising all available bird count data for South African estuaries.

Table 2.3. Existing information on fish and bird communities for South African estuaries (i.e. excluding studies of the biology of selected species). "Harrison" refers to an unpublished data set. CWAC (Co-ordinated Waterbird Counts) means that the estuary is counted twice yearly, since ca. 1993 or later.

No	ESTUARY	Type	Size (ha)	Fish	Birds
1	Orange (Gariep)	R	974.52	Harrison; Seaman & van As 1998; Lamberth unpubl 2003	Grindley 1959; Ryan & Cooper 1985; Williams 1986
2	Olifants	O	701.69	Harrison, Lamberth unpubl 94-99, 04	Ryan & Cooper 1985; CWAC
2a	Verlorenvlei	C		Harrison; Lamberth unpubl .2002	
3	Berg (Groot)	O	3615	Harrison; Bennet 1994; Lamberth unpubl; Clark unpubl 2003	Velasquez *et al.* 1991; Hockey 1993; Kalejta & Hockey 1994; CWAC
4	Rietvlei/Diep	C	515	Lamberth unpubl	Ryan *et al.* 1988; CWAC
5	Houtbaai	R		Harrison	
6	Wildevoëlvlei	C	75.79	Harrison, Lamberth unpubl.	CWAC; Turpie 2003
7	Bokramspruit	C			
8	Schuster	C		Harrison	
9	Krom	C		Harrison	
10	Silvermine	C	6.52	Harrison, Southern Waters unpubl.	
11	Sand	C	155.48	Gaigher 1979; Harrison; Clark *et al.* 1994, Lamberth unpubl., Morant 1991, Quick & Harding 1994 Harrison 1998	Ryan *et al.* 1988; CWAC
12	Eerste	C	10.2	Harrison; Morant 1991; Clark *et al.* 1994, Harrison 1998; Lamberth unpubl.	Ryan *et al.* 1988
13	Lourens	C	7.09	Harrison, Harrison 1998; Lamberth unpubl.	Ryan *et al.* 1988
14	Sir Lowry's Pass	C	2.95	Harrison	
15	Steenbras	O	1.88	Harrison	
16	Rooiels	C	10.84	Harrison, Lamberth unpubl.	Ryan *et al.* 1988
17	Buffels (Oos)	C	17.28	Harrison	Ryan *et al.* 1988
18	Palmiet	O	33	Harrison, Lamberth unpubl.	Ryan *et al.* 1988
19	Bot/Kleinmond	L	1698.4	Koop *et al.* 1983; Bennet *et al.* 1985, Lamberth unpubl monthly data 01-04	Heyl & Currie 1985; Ryan *et al.* 1988, CWAC
20	Onrus	C	41.13	Harrison, Lamberth unpubl	Ryan *et al.* 1988
21	Klein	L	2958.9	Harrison, Lamberth unpubl monthly data 01-04	Ryan *et al.* 1988
22	Uilskraals	C	104.7	Harrison	Ryan *et al.* 1988
23	Ratel	C	10	Harrison	Ryan *et al.* 1988
24	Heuningnes	O	172.51	Harrison, Lamberth unpubl. 95-04	Ryan *et al.* 1988; CWAC
25	Klipdrifsfontein	C		Harrison	Ryan *et al.* 1988
26	Breë	O	455.28	Harrison; Lamberth 2001; Lamberth unpubl 97-04 (quarterly)	Ryan *et al.* 1988; Turpie 2001
27	Duiwenhoks	O	203.07	Harrison; Lamberth unpubl 02-04 (quarterly)	Underhill & Cooper 1984
28	Goukou (Kaffirkuils)	O	154.76	Harrison; Lamberth unpubl 02-04 (quarterly)	Underhill & Cooper 1984
29	Gourits	O	112.58	Harrison; Lamberth unpubl 02-04 (quarterly)	Underhill & Cooper 1984
30	Blinde	C		Harrison	Underhill & Cooper 1984
31	Hartenbos	C	40.59	Harrison	Underhill & Cooper 1984
32	Klein Brak	C	96	Harrison	Underhill & Cooper 1984
33	Groot Brak	C	113.92	Harrison	Underhill & Cooper 1984
34	Maalgate	C	13.5	Harrison	
35	Gwaing	C		Harrison	
36	Kaaimans	O	8	Harrison	Underhill & Cooper 1984

No	ESTUARY	Type	Size (ha)	Fish	Birds
37	Wilderness	L		Hall *et al.* 1987; Harrison; Russel 1996	Underhill & Cooper 1984; CWAC
38	Swartvlei	L	1076.63	Kok & Whitfeld 1986; Whitfield 1988; Harrison; Russel 1996	Underhill & Cooper 1984; CWAC
39	Goukamma	C	270	Harrison	Underhill & Cooper 1984
40	Knysna	Bay	3594	Harrison	Underhill & Cooper 1984; CWAC
41	Noetsie	C	8	Harrison	Underhill & Cooper 1984
42	Piesang	C	92.24	Harrison	Underhill & Cooper 1984
43	Keurbooms	O	295.17	Harrison	Underhill & Cooper 1984; CWAC
44	Matjies/Bitou	C		Harrison	Underhill & Cooper 1984
45	Sout (Oos)	O	52.22	Harrison	Underhill & Cooper 1984
46	Groot (Wes)	C	39.28	Harrison	Underhill & Cooper 1984
47	Bloukrans	R		Harrison	
48	Lottering	R	17	Harrison	
49	Elandsbos	R	6	Harrison	
50	Storms	R		Harrison	Underhill & Cooper 1984
51	Elands	R		Harrison	
52	Groot (Oos)	R		Harrison	
53	Tsitsikamma	C		Harrison	
54	Klipdrif	C		Harrison	Underhill & Cooper 1984
55	Slang	C		Harrison	
56	Krom Oos (Kromme)	O	240.34	Melville-Smith 1981; Marais 1983a; Hanekom & Baird 1984; Harrison; Cloete 1990; Strydom 1995	Underhill & Cooper 1984
57	Seekoei	C	132.22	Dundas 1994	Underhill & Cooper 1984
58	Kabeljous	C	117.94	Harrison, Dundas 1994	Underhill & Cooper 1984
59	Gamtoos	O	467.03	Marais 1982a,b, 1983b; Harrison; Whitfield & Wood 2003	Shewell 1950; Underhill & Cooper 1984
60	Van Stadens	C	28	Harrison, Dundas 1994	Underhill & Cooper 1984
61	Maitland	C	0.2	Harrison	Underhill & Cooper 1984
62	Swartkops	O	499	Winter 1979; Melville-Smith & Baird 1980; Marais & Baird 1980; Harrison; Daniel 1994	Every 1973; Underhill & Cooper 1984; Martin & Baird 1987; Martin 1991; Tree & Martin 1993; CWAC
63	Coega (Ngcura)	C	10.14	Harrison	Every 1970; Underhill & Cooper 1984
64	Sundays	O	173.37	Beckley 1984; Hay 1985; Harrison	Underhill & Cooper 1984
65	Boknes	C	27	Harrison	Underhill & Cooper 1984
66	Bushmans	O	213	Harrison	Underhill & Cooper 1984
67	Kariega	O	198	Harrison; Paterson & Whitfield 2000; Whitfield & Wood 2003+M235	Underhill & Cooper 1984
68	Kasuka	C	38	Harrison	Underhill & Cooper 1984
69	Kowie	O	118.63	Harrison	Underhill & Cooper 1984
70	Rufane	C		Harrison	
71	Riet	C	73.06	Harrison	Scott 1954; Kalejta
72	Kleinemond Wes	C	80	Harrison	Underhill & Cooper 1984
73	Kleinemond Oos	C	35	Harrison; Cowley 1998, Vorwerk *et al.* 2001; Cowley & Whitfield 2001; Cowley *et al.* 2001	Underhill & Cooper 1984
74	Klein Palmiet	C		Vorwerk *et al.* 2001	
75	Great Fish	O	365.68	Harrison; TerMorshuizen *et al.* 1996,1997; Whitfield & Wood 2003; Vorwerk *et al.* 2001	Underhill & Cooper 1984
76	Old woman's	C	25.12	Harrison	Underhill & Cooper 1984
77	Mpekweni	C	141.41	Harrison; Vorwerk *et al.* 2001	Underhill & Cooper 1984
78	Mtati	C	124.2	Harrison; Vorwerk *et al.* 2001	Underhill & Cooper 1984
79	Mgwalana	C	123.62	Harrison; Vorwerk *et al.* 2001	Underhill & Cooper 1984
80	Bira	C	97.49	Harrison; Vorwerk *et al.* 2001	Underhill & Cooper 1984

No	ESTUARY	Type	Size (ha)	Fish	Birds
81	Gqutywa	C	51.64	Harrison; Vorwerk *et al.* 2001	Underhill & Cooper 1984
82	Blue Krans	C	2.54		
83	Mtana	C	15.69	Harrison	Underhill & Cooper 1984
84	Keiskamma	O	493.84	Harrison; Vorwerk *et al.* 2001	Underhill & Cooper 1984
85	Ngqinisa	C	12.67	Harrison	Underhill & Cooper 1984
86	Kiwane	C	18.8	Harrison	
87	Tyolomnqa	C	107.44	Harrison	Underhill & Cooper 1984
88	Shelbertsstroom	C		Harrison	
89	Lilyvale	C	2.3	Harrison	
90	Ross' Creek	C		Harrison	
91	Ncera	C	28.4	Harrison	Underhill & Cooper 1984
92	Mlele	C	3.6	Harrison	Underhill & Cooper 1984
93	Mcantsi	C	9	Harrison	Underhill & Cooper 1984
94	Gxulu	C	48.5	Harrison	Underhill & Cooper 1984
95	Goda	C	17.2	Harrison	Underhill & Cooper 1984
96	Hlozi	C	0.7	Harrison	Underhill & Cooper 1984
97	Hickman's	C	4.3	Harrison	Underhill & Cooper 1984
98	Buffalo	O	98	Harrison	Underhill & Cooper 1984
99	Blind	C	0.5	Harrison	
100	Hlaze	C	1.5	Harrison	
101	Nahoon	O	57.7	Harrison	Underhill & Cooper 1984
102	Qinira	C	72.13	Harrison	Underhill & Cooper 1984
103	Gqunube	O	53.4	Harrison	Underhill & Cooper 1984
104	Kwelera	O	50.1	Harrison	Underhill & Cooper 1984
105	Bulura	C	35.5	Harrison	Underhill & Cooper 1984
106	Cunge	C	0.5	Harrison	
107	Cintsa	C	29.3	Harrison	Underhill & Cooper 1984
108	Cefane	C	82.7	Harrison	Underhill & Cooper 1984
109	Kwenxura	C	29.1	Harrison	Underhill & Cooper 1984
110	Nyara	C	17.1	Harrison	Underhill & Cooper 1984
111	Haga-haga	C	3.4	Harrison	
112	Mtendwe	C	11.23	Harrison	
113	Quko	C	36.18	Harrison	Underhill & Cooper 1984
114	Morgan	C	24	Harrison	Underhill & Cooper 1984
115	Cwili	C	1.2	Harrison	Turpie unpubl data
116	Great Kei	O	222.4	Plumstead *et al.* 1985; Harrison	Underhill & Cooper 1984; This study
117	Gxara	C	23.9	Harrison	This study
118	Ngogwane	C	9.12	Harrison	This study
119	Qolora	C	22.9	Harrison	Underhill & Cooper 1984; This study
120	Ncizele	C	6.635	Harrison	This study
121	Kobonqaba	O	26.4	Harrison	This study
122	Nxaxo/Ngqusi	O	159.48	Harrison	Underhill & Cooper 1984; This study
123	Cebe	C	16.53	Harrison	Underhill & Cooper 1984; This study
124	Gqunqe	C	17.94		This study
125	Zalu	C	12.36		This study
126	Ngqwara	C	19.36	Harrison	Underhill & Cooper 1984; This study
127	Sihlontlweni/Gcini	C	11.01		This study
128	Qora	O	89.63	Harrison	This study
129	Jujura	C	4.77	Harrison	This study
130	Ngadla	C	13.884	Harrison	
131	Shixini	O	22.1	Harrison	This study

No	ESTUARY	Type	Size (ha)	Fish	Birds
132	Nqabara	O	109.66		
133	Ngoma/Kobule	C	10.11		
134	Mendu	C	23.83		
135	Mbashe	O	131.95	Plumstead *et al.* 1989a; Plumstead 1990; Harrison	Underhill & Cooper 1984; This study
136	Ku-Mpenzu	C	13.38	Harrison	This study
137	Ku-Bhula/Mbhanyana	C	7.6	Harrison	This study
138	Ntlonyane	C	41.34	Harrison	This study
139	Nkanya	C	15.47	Harrison	This study
140	Xora	O	150.58	Harrison	This study
141	Bulungula	C	18.4		Underhill & Cooper 1984; This study
142	Ku-amanzimuzama	C	3.65		This study
143	Mncwasa	C	19.216		This study
144	Mpako	C	13.51		This study
145	Nenga	C	10.01	Harrison	This study
146	Mapuzi	C	15.9	Harrison	This study
147	Mtata	O	168.79	Plumstead *et al.* 1985; Harrison	This study
148	Mdumbi	O	76.07	Harrison	This study
149	Lwandilana	C	9.69		This study
150	Lwandile	C	22.2		This study
151	Mtakatye	O	116.81		This study
152	Hluleka/Majusini	C	14.9		This study
153	Mnenu	C	90.52		This study
154	Mtonga	C	32.2		This study
155	Mpande	C	15.04	Harrison	This study
156	Sinangwana	C	13.2	Harrison	This study
157	Mngazana	O	224.85	Harrison	This study
158	Mngazi	C	17.1	Harrison	This study
159	Bululo	C	12.62	Harrison	This study
160	Mtambane	C	10.94		This study
161	Mzimvubu	R	150.99	Harrison	This study
162	Ntlupeni	C	4.37	Harrison	This study
163	Nkodusweni	C	32.6		This study
164	Mntafufu	O	24.07	Plumstead *et al.* 1991; M38Harrison	This study
165	Mzintlava	O	23.06		This study
166	Mzimpunzi	C	5.08		This study
167	Mbotyi	C	50.39	Harrison	This study
168	Mkozi	C	4.01		This study
169	Myekane	C	1.92		This study
170	Lupatana	C	3.55		This study
171	Mkweni	C	7		This study
172	Msikaba	O	15.13	Harrison	This study
173	Mgwegwe	C	8.79	Harrison	This study
174	Mgwetyana	C	3.28	Harrison	This study
175	Mtentu	O	52.93	Harrison	This study
176	Sikombe	C	11.48		This study
177	Kwanyana	C	7.13		This study
178	Mnyameni	C	27.92		This study
179	Mpahlanyana	C	3.85		This study
180	Mpahlane	C	3.92		This study
181	Mzamba	O	70.94	Harrison	This study
182	Mtentwana	C	11.43		This study
183	Mtamvuna	C	63.53	Begg 1984a/b	Ryan *et al.* 1986
184	Zolwane	C	0.5	Begg 1984a/b	Ryan *et al.* 1986

No	ESTUARY	Type	Size (ha)	Fish	Birds
185	Sandlundlu	C	4	Harrison; Begg 1984a/b	Ryan *et al.* 1986
186	Ku-boboyi	C	1.1	Harrison; Begg 1984a/b	Ryan *et al.* 1986
187	Tongazi	C	0.8	Harrison; Begg 1984a/b	Ryan *et al.* 1986
188	Kandandhlovu	C	1.8	Harrison; Begg 1984a/b	Ryan *et al.* 1986
189	Mpenjati	C	11.6	Harrison; Begg 1984a/b	Ryan *et al.* 1986
190	Umhlangankulu	C	9.7	Harrison; Begg 1984a/b	Ryan *et al.* 1986
191	Kaba	C	2.4	Harrison; Begg 1984a/b	Ryan *et al.* 1986
192	Mbizana	C	12.4	Harrison; Begg 1984a/b	Ryan *et al.* 1986
193	Mvutshini	C	0.9	Harrison; Begg 1984a/b	Ryan *et al.* 1986
194	Bilanhlolo	C	2.6	Harrison; Begg 1984a/b	Ryan *et al.* 1986
195	Uvuzana	C	0.6	Harrison; Begg 1984a/b	Ryan *et al.* 1986
196	Kongweni	C	1.4	Harrison; Begg 1984a/b	Ryan *et al.* 1986
197	Vungu	C	1.1	Harrison; Begg 1984a/b	Ryan *et al.* 1986
198	Mhlangeni	C	3.6	Harrison; Begg 1984a/b	Ryan *et al.* 1986
199	Zotsha	C	7.3	Harrison; Begg 1984a/b, Harrison & Whitfield 1995	Ryan *et al.* 1986
200	Boboyi	C	1.3	Harrison; Begg 1984a/b	Ryan *et al.* 1986
201	Mbango	C	0.9	Harrison; Begg 1984a/b	Ryan *et al.* 1986
202	Mzimkulu	O	74	Harrison; Begg 1984a/b	Ryan *et al.* 1986
203	Mtentweni	C	8	Harrison; Begg 1984a/b	
204	Mhlangamkulu	C	3.9	Harrison; Begg 1984a/b	
205	Damba	C	1.7	Harrison; Begg 1984a/b; Harrison & Whitfield 1995	
206	Koshwana	C	1.2	Harrison; Begg 1984a/b	
207	Intshambili	C	1.7	Harrison; Begg 1984a/b	
208	Mzumbe	C	15.8	Harrison; Begg 1984a/b	
209	Mhlabatshane	C	2.3	Harrison; Begg 1984a/b	
210	Mhlungwa	C	3.1	Harrison; Begg 1984a/b	Ryan *et al.* 1986
211	Mfazazana	C	2.1	Harrison; Begg 1984a/b	Ryan *et al.* 1986
212	Kwa-Makosi	C	2.5	Harrison; Begg 1984a/b	Ryan *et al.* 1986
213	Mnamfu	C	1.3	Harrison; Begg 1984a/b	Ryan *et al.* 1986
214	Mtwalume	C	24.8	Harrison; Begg 1984a/b	Ryan *et al.* 1986
215	Mvuzi	C	0.8	Harrison; Begg 1984a/b	Ryan *et al.* 1986
216	Fafa	C	29	Harrison; Begg 1984a/b	Ryan *et al.* 1986
217	Mdesingane	C	0.4	Begg 1984a/b	Ryan *et al.* 1986
218	Sezela	C	12	Harrison; Begg 1984a/b; Ramm et al. 1987	Ryan *et al.* 1986
219	Mkumbane	C	0.3	Harrison; Begg 1984a/b	Ryan *et al.* 1986
220	Mzinto	C	7	Harrison; Begg 1984a/b	Ryan *et al.* 1986
221	Mzimayi	C	1	Harrison; Begg 1984a/b	Ryan *et al.* 1986
222	Mpambanyoni	C	2.3	Harrison; Begg 1984a/b	Ryan *et al.* 1986
223	Mahlongwa	C	5.9	Harrison; Begg 1984a/b	Ryan *et al.* 1986
224	Mahlongwana	C	6.8	Harrison; Begg 1984a/b	Ryan *et al.* 1986
225	Mkomazi	O	77.9	Harrison; Begg 1984a/b	Ryan *et al.* 1986
226	Ngane	C	1.4	Begg 1984a/b	Ryan *et al.* 1986
227	Umgababa	C	17.6	Begg 1984a/b	Ryan *et al.* 1986
228	Msimbazi	C	13.2	Harrison; Begg 1984a/b	Ryan *et al.* 1986
229	Lovu	C	10.5	Harrison; Begg 1984a/b	Ryan *et al.* 1986
230	Little Manzimtoti	C	1.5	Harrison; Begg 1984a/b	Ryan *et al.* 1986
231	Manzimtoti	C	6.7	Harrison; Begg 1984a/b	Ryan *et al.* 1986
232	Mbokodweni	C	7.2	Harrison; Begg 1984a/b	Ryan *et al.* 1986
233	Sipingo	O	6.8	Harrison; Begg 1984a/b	Ryan *et al.* 1986
234	Durban Bay	Bay		Harrison; Begg 1984a/b; Harris & Cyrus 1999	Ryan *et al.* 1986
235	Mgeni	C	48	Harrison; Begg 1984a/b	Ryan *et al.* 1986, CWAC

No	ESTUARY	Type	Size (ha)	Fish	Birds
236	Mhlanga	C	100.1	Harrison: Whitfield 1980a; Begg 1984a/b: Harrison & Whitfield 1995	Ryan *et al.* 1986
237	Mdloti	C	58.1	Harrison: Begg 1984a/b	Ryan *et al.* 1986
238	Tongati	C	37.3	Harrison: Begg 1984a/b	Ryan *et al.* 1986
239	Mhlali	C	21	Harrison: Begg 1984a/b	Ryan *et al.* 1986
240	Seteni	C	1.1	Harrison: Begg 1984a/b	Ryan *et al.* 1986
241	Mvoti	R	18.4	Harrison: Begg 1984a/b	Ryan *et al.* 1986
242	Mdlotane	C	25.42	Harrison: Begg 1984a/b	Ryan *et al.* 1986
243	Nonoti	C	18	Harrison: Begg 1984a/b	Ryan *et al.* 1986
244	Zinkwasi	C	71.16	Harrison: Begg 1984a/b	Ryan *et al.* 1986
245	Tugela/Thukela	R	55	Harrison: Begg 1984a/b	Ryan *et al.* 1986, CWAC
246	Matigulu/Nyoni	O	192	Harrison: Begg 1984a/b	Ryan *et al.* 1986
247	Siyaya	C	7.69	Harrison: Begg 1984a/b; Van der Elst et al. 1999	Ryan *et al.* 1986
248	Mlalazi	O	202	Harrison: Begg 1984a/b	Ryan *et al.* 1986, CWAC
249	Mhlathuze	Bay	1691	Harrison: Begg 1984a/b; Weerts & Cyrus 1998/9+M3	Cyrus 1998/9b
250	Richard's Bay	Bay	1800	Harrison: Begg 1984a/b: Harris & Cyrus 1997	Ryan *et al.* 1986, CWAC
251	Nhlabane	L	14.4	Harrison: Begg 1984a/b; Chater & van der Elst 1995+M3	Ryan *et al.* 1986
252	Mfolozi	R	180	Harrison: Begg 1984a/b	Ryan *et al.* 1986
253	St Lucia	L	38290	Harrison: Begg 1984a/b; Harris & Cyrus 1995	Berruti 1980a,b; Ryan *et al.* 1986, CWAC
254	Mgobezeleni	L	1.3	Harrison: Begg 1984a/b	Ryan *et al.* 1986
255	Kosi	L	3500	Harrison: Begg 1984a/b; Harris *et al.* 1995	Ryan *et al.* 1986

2.7 Creation of a database

Available data on birds and invertebrates have been collated in spreadsheet databases. A MS Access database was originally designed for the purpose, but then deemed unnecessary, as a simple spreadsheet would suffice for the available data. The invertebrate database only includes data that were made available to the project. Other data exist in private collections. The fish data were not collated due to a shortage of resources: most of these data are literally still in raw form, and the largest data set is not yet available for public use. It was thus decided to retain an emphasis on birds and invertebrates. Using these data, the importance rating database was updated, as described in this report.

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3. A FIELD COUNT OF THE BIRDS OF THE TRANSKEI COAST AND ESTUARIES: JANUARY-FEBRUARY 2002

Jane Turpie, Paul Martin & Charles Pemberton

3.1 Introduction

This study forms part of a project entitled "Improving the Biodiversity Importance Rating of South Africa's Estuaries", which in turn forms part of a larger Water Research Commission Project entitled "Information requirements for the implementation of resource directed measures (RDM) for estuaries". The RDM methodology entails determining the reserve of water supply required for the ecological functioning of estuaries, and is based on the health and importance of the estuary (Taljaard *et al.* 2002). The conservation importance status of each estuary must necessarily be seen in the context of the attributes of all South African estuaries, as relative importance cannot be determined in isolation. Thus importance scores for all South African estuaries have already been derived on the basis of the existing information on plant, invertebrate, fish and bird populations (Turpie *et al.* 2002). These scores are rough, however, since data are patchy for some taxa. In the case of bird data, importance scores have been based on a series of counts that took place between 1979 and 1981. These counts did not include the Transkei coast (Turpie 1995), which contains about a quarter of South Africa's estuaries. The aim of this project was to fill the data gap by providing comparable bird count data for Transkei estuaries.

3.2 Methods

The Transkei estuaries were counted between 21 January and 9 February 2002. The coast was divided into three sections (Fig. 1), each of which was tackled by one counter with an assistant. *Paul Martin counted the northern section, Charles Pemberton counted the central* section, and Jane Turpie counted the southern section.

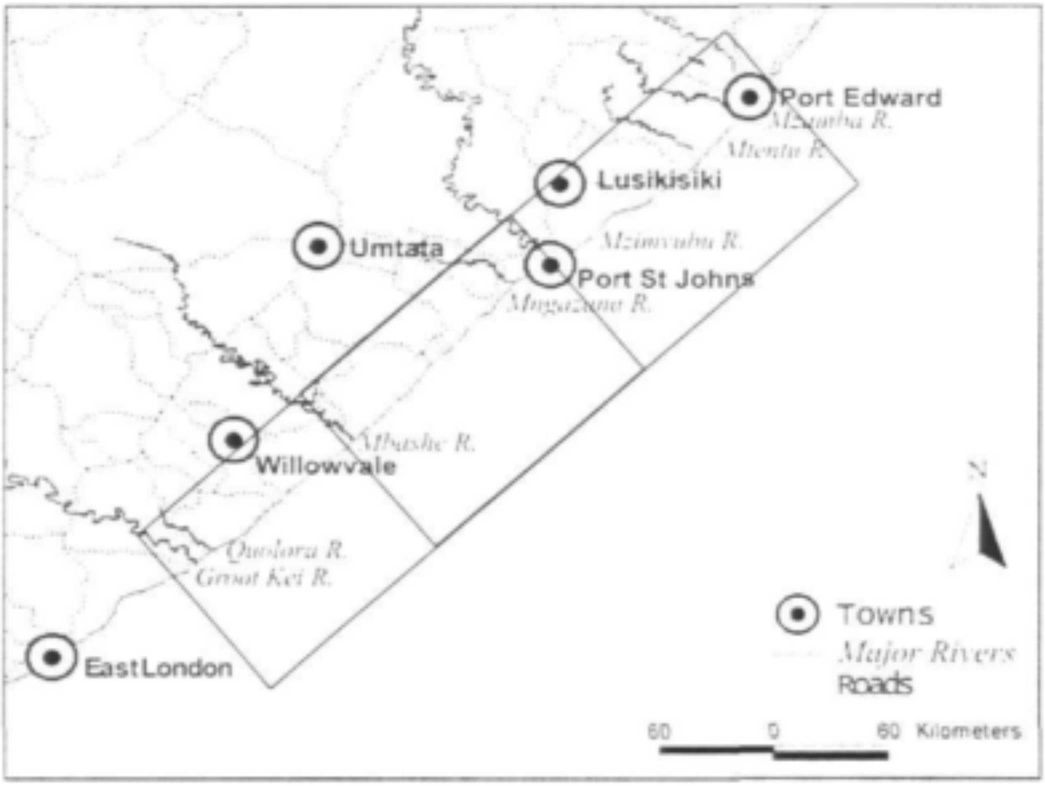

Figure 3.1. Map of the study area showing the three counting sections

Counts included both estuaries and the rest of the coastline, and concentrated on waterbird species. The whole coast was covered on foot, and walking was timed so that arrival at estuaries would coincide with low tide as far as possible. Large estuaries were counted from canoes as far as possible, but canoes were not always available, in which case, the estuaries were counted on foot. A total of 55 estuaries as recognised by Whitfield 2000, were counted. Numerous small river mouths or very small estuaries were also encountered, and birds counted in these were recorded separately in case of future information requirements, but numbers are included with the coastal counts in this report.

Coastal counts were included for completeness, as counts of other sections of coast have included these. For coastal counts, the coast was counted by habitat type: sandy, rocky and mixed shores, and small river mouths. Coastal counts were only carried out over part of the central section.

Positions of estuaries and points between counting sections (e.g. breaks in habitat type) were recorded with GPS.

3.3 Results and discussion

A total of 3265 waterbirds and 41 waterbird species were recorded along the entire coast, of which 2206 birds (68%) and 40 species were recorded in estuaries (Table 1). Of the 41 species, only Ruddy Turnstone was never recorded in an estuary.

Terns were included in estuary counts, but were usually roosting at the mouths of estuaries. These roosts were associated with the larger estuaries, usually located on sandbanks and rocky outcrops at the mouth, where birds were able to roost on areas surrounded by water (giving security). Roosts were found at Mkozi, Mzimvubu, Mgazi and Mbashe. Small roosts were also found at Mnenu and Nxaxo. Tern roosts were also found along the open coast.

Excluding terns, only 983 birds were counted in estuaries in total. Of these, 608 (62%) were waders, and the most commonly recorded species was Whitefronted Plover, which occurred in 62% of estuaries counted. Common Sandpiper and Greenshank each occurred in 44% of estuaries. Water Dikkop was also common, occurring in 38% of estuaries. Kingfishers (121 counted) were the next most abundant group, and Pied Kingfisher was the second most widespread species, occurring in 47% of estuaries. Wagtails were the third most common group, with Cape Wagtail occurring in 35% of estuaries. African Pied wagtail was only recorded in the subtropical part of the coast (north of Mbashe), where it was as common as Cape Wagtail. Waterfowl were only recorded in 18% of estuaries, but this is also partly an artefact of sampling methods, in that waterfowl were mostly found in the upper reaches, and were usually only encountered when a count was done by canoe. Fish Eagles were recorded in 22% of estuaries. Whitebreasted Cormorants and Grey Herons were also frequently encountered.

The composition of the waders was fairly interesting. Waders were dominated by Whitefronted Plovers, Common Sandpipers, Greenshank, Threebanded Plovers and Ringed Plovers, all of which peck very small prey from the surface of exposed sandy or muddy substrates. Species which probe and/or feed predominantly on polychaetes, such as Curlew Sandpipers, Whimbrels, Godwits and Grey Plovers, were scarce. This pattern is not surprising, since preliminary sampling of estuaries suggested that most were very unproductive in terms of benthic macrofauna. However, numbers were also low in some estuaries that did appear to be productive, such as Shixini. Mangrove estuaries, presumably the most productive systems, tended to have higher numbers of waders, and of birds in general.

A total of 52 African Black Oystercatchers, a red data species, were counted on the Transkei coast, of which 17 were recorded in estuaries. Most Oystercatchers were recorded in the Warm temperate biogeographical zone south of the Mbashe, but 5 were recorded in the northern part of the coast, at Msikaba and Mntafufu. Breeding was recorded on several occasions. The total population of Oystercatchers in the country is about 5000 birds, of which 280 (including this count) are found in estuaries.

Another red data species recorded was the Mangrove Kingfisher, but only 7 were counted, in four estuaries. This species is not common on the Transkei coast, occurring only in Mangrove estuaries, with Nxaxo estuary being the southernmost point of its range. Due to its seasonal movements, summer is not the ideal time for counting this species, and it is likely that this count is an underestimate. The Transkei population is likely to be a large proportion of the total South African population.

Waterfowl numbers were particularly low. A number of factors might contribute to this, including low levels of estuarine productivity and hunting.

Both Giant Kingfishers and Hamerkops were far more common in the north of the range than further south. Both Whitefronted Plovers and Sanderlings are more common towards the south, suggesting more productive beach areas in the south.

In general, larger estuaries supported more waterbirds than smaller ones, although the pattern was somewhat dichotomous for permanently open estuaries (Fig. 2). The two estuaries with the highest bird counts in Fig. 2 are the Nxaxo estuary, which attracted large numbers of roosting birds to its mouth area, and the Qora. Excluding these two estuaries there was no clear trend between estuary size and number of birds for permanently open estuaries.

Table 3.1. Summary of bird counts along the Transkei coast in Jan-Feb 2002. Counts are divided into three sections as follows: North – Mtentwana to Mzimvubu, Mid = Mgazi to Mbanyane, South = Mbashe to Great Kei.

	Estuaries				Coast				Estuaries + coast			
	North	Mid	South	Total	North	Mid	South	Total	North	Mid	South	Total
Whitebreasted Cormorant	8	4	28	**40**	14	19	17	**50**	22	23	45	**90**
Grey Heron	2	10	3	**15**			3	**3**	2	10	6	**18**
Purple Heron	4			**4**				**0**	4	0	0	**4**
Little Egret	1	5		**6**				**0**	1	5	0	**6**
Hamerkop	4	1	2	**7**	7			**7**	11	1	2	**14**
Hadeda Ibis		1	7	**8**	2			**2**	2	1	7	**10**
Egyptian Goose	7	10	3	**20**					7	10	3	**20**
Yellowbilled Duck	5	2	5	**12**					5	2	5	**12**
African Black Duck	1		13	**14**					1		13	**14**
Spurwinged Goose	1	2	10	**13**					1	2	10	**13**
African Fish Eagle	8	2	6	**16**			1	**1**	8	2	7	**17**
African Black Oystercatcher	5		12	**17**	2	10	23	**35**	7	10	35	**52**
Turnstone					11		62	**73**	11		62	**73**
Knot			2	**2**							2	**2**
Ringed Plover	3	8	15	**26**	5			**5**	8	8	15	**31**
Whitefronted Plover	40	33	64	**137**	54	15	66	**135**	94	48	130	**272**
Threebanded Plover	23	6	9	**38**	6		13	**19**	29	6	22	**57**
Greater Sand Plover		1	1	**2**						1	1	**2**
Grey Plover	2	1		**3**	2		1	**3**	4	1	1	**6**
Blacksmith Plover	9	5	4	**18**					9	5	4	**18**
Common Sandpiper	46	39	25	**110**	9		2	**11**	55	39	27	**121**
Wood Sandpiper	1	2	8	**11**					1	2	8	**11**
Greenshank	11	35	26	**72**	3	1	1	**5**	14	36	27	**77**
Curlew Sandpiper			3	**3**							3	**3**
Little Stint	1			**1**					1			**1**
Sanderling	33		42	**75**	62	17	248	**327**	95	17	290	**402**
Whimbrel		12	5	**17**		4	4	**8**		16	9	**25**
Bartailed Godwit	1			**1**					1			**1**
Water Dikkop	51	9	15	**75**	9			**9**	60	9	15	**84**
Kelp Gull		1	7	**8**	2		18	**20**	2	1	25	**28**
Swift Tern	107	5		**112**	32		50	**82**	139	5	50	**194**
Sandwich Tern	17	4		**21**			15	**15**	17	4	15	**36**
Common Tern	641	175	171	**987**			71	**71**	641	175	242	**1058**
Little Tern			103	**103**			21	**21**			124	**124**
Pied Kingfisher	22	12	30	**64**			12	**12**	22	12	42	**76**
Giant Kingfisher	13		3	**16**	8		2	**10**	21		5	**26**
Halfcollared Kingfisher	10		11	**21**	3			**3**	13		11	**24**
Malachite Kingfisher	11	2		**13**	1			**1**	12	2		**14**
Mangrove Kingfisher	4	1	2	**7**					4	1	2	**7**
African Pied Wagtail	21	14		**35**	3			**3**	24	14		**38**
Cape Wagtail	20	13	23	**56**	77		51	**128**	97	13	74	**184**
TOTAL birds	1133	415	658	**2206**	312	66	681	**1059**	1445	481	1339	**3265**
No. of Species	33	29	31	**40**	20	6	20	**27**	53	31	35	**41**

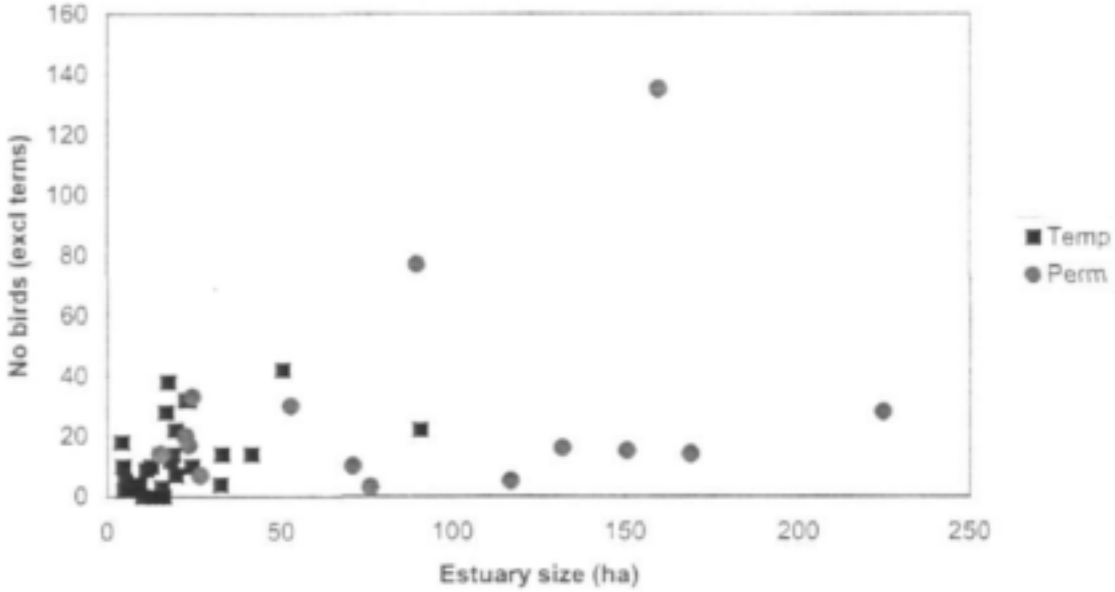

Figure 3.2. Relationship between estuary size and numbers of birds, excluding terns, for permanently open and temporarily open estuaries.

Permanently open estuaries did not support more waterbirds than temporarily open estuaries of the same size. Ordination and multi-dimensional scaling analysis did not reveal any significant patterns in bird communities within the Transkei estuaries. Indeed, even though permanently open estuaries had more intertidal area, they did not support much higher numbers or variety of waders, as might have been expected.

In the context of the estuarine birds around the South African coast, the Transkei contributes only 0.8% of the entire population. The rest of the Eastern Cape accounts for a further 5.7%. 64.5% are in Western and Northern Cape estuaries, and 29% are in KwaZulu Natal. The Transkei estuaries support a very low aggregate population as well as low populations on individual estuaries. The numbers of birds per estuary are low compared to areas both to the west and east of the Transkei (Fig. 3), a pattern which can at least partially be explained by the size of estuaries in this area (Fig. 4).

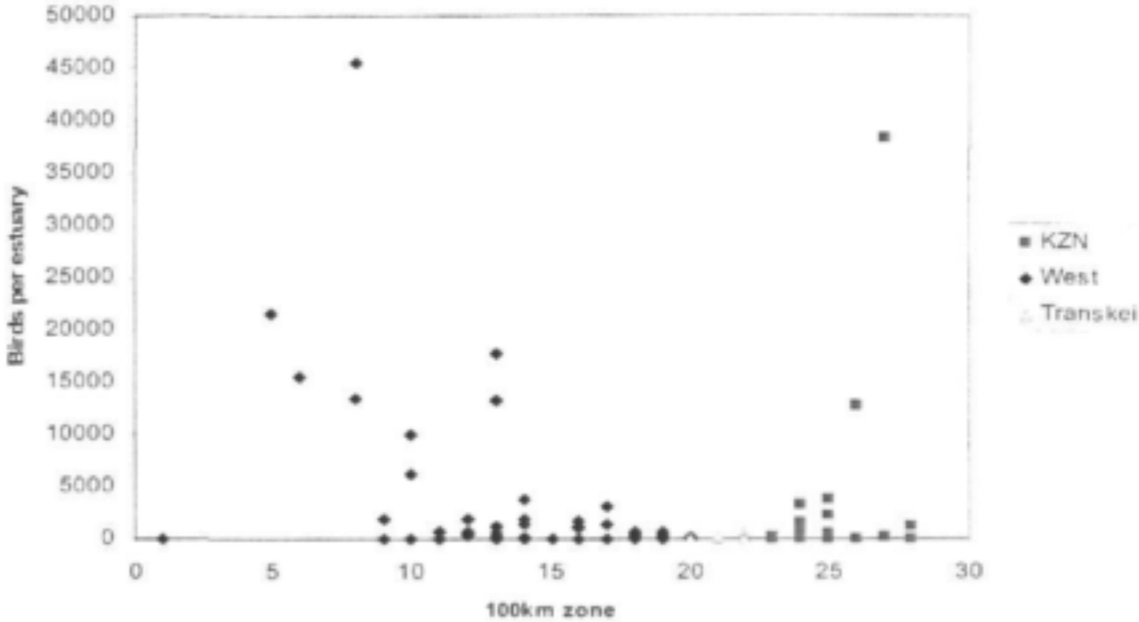

Figure 3.3. Number of birds in estuaries in 30 100km zones around the South African coast, highlighting the Transkei coastal area. This excludes L St Lucia. Note that the highest count (Berg estuary) includes a comprehensive floodplain count.

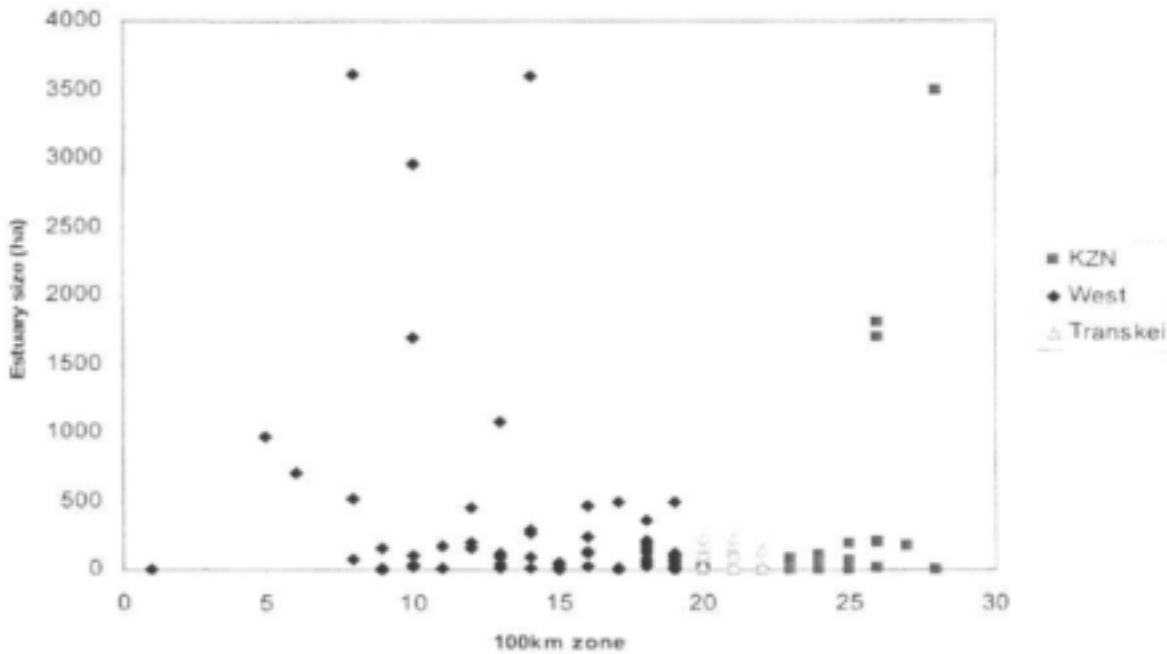

Figure 3.4. Sizes of estuaries in 30 100km zones around the coast, highlighting the Transkei area. This excludes L St Lucia.

3.4 Conclusion

Transkei estuaries generally have low numbers of birds, but several do contain reasonable numbers, and several estuaries support important bird species. The estuarine importance rating index has up till now assumed a minimum score for all estuaries for which there are no data. The count data produced here will be incorporated into the index. On the whole, there is unlikely to be any major change in the importance ratings of non-Transkei estuaries as a result of the data generated in this study, due to the small numbers of birds involved. However, the importance ratings for Transkei estuaries will be known, and a few of the larger estuaries are expected to be fairly important for birds, especially those supporting rare species such as Mangrove Kingfisher.

3.5 References

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4. A FIELD STUDY OF THE INTERTIDAL INVERTEBRATE FAUNA OF 16 WARM TEMPERATE ESTUARIES

David Knox, Barry Clark & Jane Turpie

4.1 Introduction

Information on the invertebrate fauna of South African estuaries is scarce compared with other taxa, and comprehensive data are only available for a handful of estuaries. This presents a challenge in determining the importance of estuaries in terms of their invertebrate populations. The development of predictive models of invertebrate community characteristics from existing data will require a large enough set of estuaries for which data are available for all groups of invertebrates. In general, the most frequent information gap is for intertidal invertebrates. This study thus concentrated on the intertidal invertebrate fauna of estuaries for which data already existed for other invertebrate communities.

Early research concentrated on intertidal taxa and their ecology (e.g. Day *et al.* 1952, Day 1964, Day 1967) and included broad distribution and habitat data in all biogeographical zones in South Africa, but quantitative data are scarce. Since then, several studies have focused on individual estuaries in each of the biogeographic zones, but these have often overlooked intertidal invertebrates and have concentrated on plankton, nekton or subtidal benthic fauna (e.g. Coetzee 1985, Hodgson 1987, McLachlan & Grindley 1974, Begg 1984). Some studies of intertidal invertebrates (e.g. Kalejta and Hockey 1991) have used a 1.0 mm mesh size to sieve samples, rather than 0.5mm that is now the standard (see Schalcher & Wooldridge 1996a). More recent invertebrate studies have concentrated on subtidal macrobenthic fauna (e.g. Teske and Wooldridge 2001), but very few have included both subtidal and intertidal macrobenthos (e.g. Bursey & Wooldridge 2002). Understanding of the physical factors affecting intertidal invertebrate communities is lacking..

In light of these data gaps, this study aims to:

1. describe and quantify species richness, community structure and distribution patterns within warm temperate estuaries;
2. identify the key factors affecting within- and between-estuary patterns; and
3. investigate the trade-offs between sampling intensity and data quality.

4.2 Study sites

Estuaries around South Africa are divided into three main biogeographic regions with water temperature being the major discriminating factor: the cool temperate region, from Walvis Bay (22° 59' S, 14° 31' E) to Cape Point (34° 22' S, 18° 30' E); the warm temperate region from Cape Point to the Mbashe River estuary (32° 17' S, 28° 54' E); and the subtropical region, from the Mbashe River estuary north to Mozambique (Whitfield 1994; Turpie *et al.* 2000). The warm temperate estuaries have higher total species richness than either the subtropical estuaries or the cool temperate estuaries (Day 1964). Because of limited resources, this study concentrated on a sample of 16 estuaries within the warm temperate region (Figure 1). The cool temperate estuaries of the west coast and the subtropical estuaries of Natal were excluded from this study to minimise the number of variables. All estuaries sampled had open connections to the sea at the time of sampling.

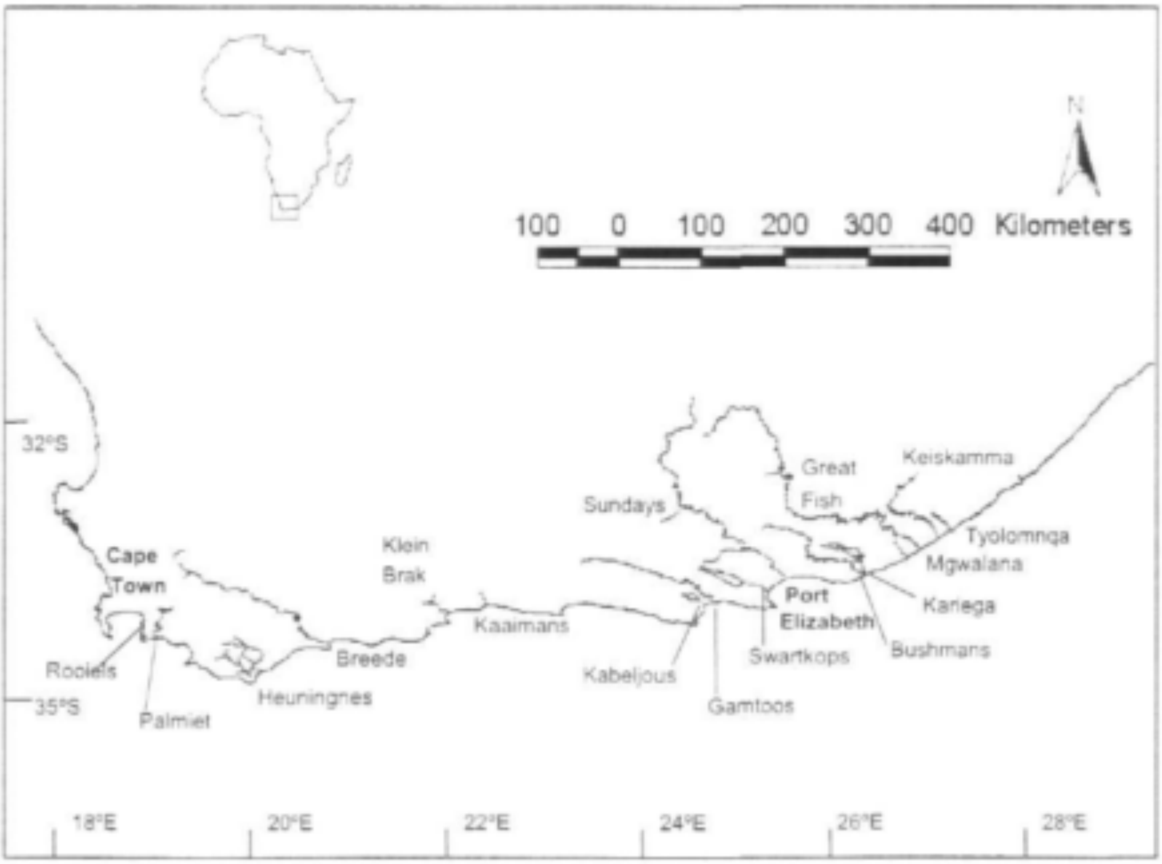


Figure 4.1. Location of the sixteen estuaries sampled in this study.

Estuaries were selected on the basis of size — to provide a suitable mix of small (<40 ha), medium (40ha-200ha), and large (>200ha) estuarine systems — and geographic location — to span the entire warm temperate region. Preference was given to those estuaries on which data for fish and subtidal benthos existed as this allows comparisons to be drawn between different faunal groups. All estuaries were classified as permanently open or temporarily closed, and other estuary types were excluded due to their being relatively rare in the region.

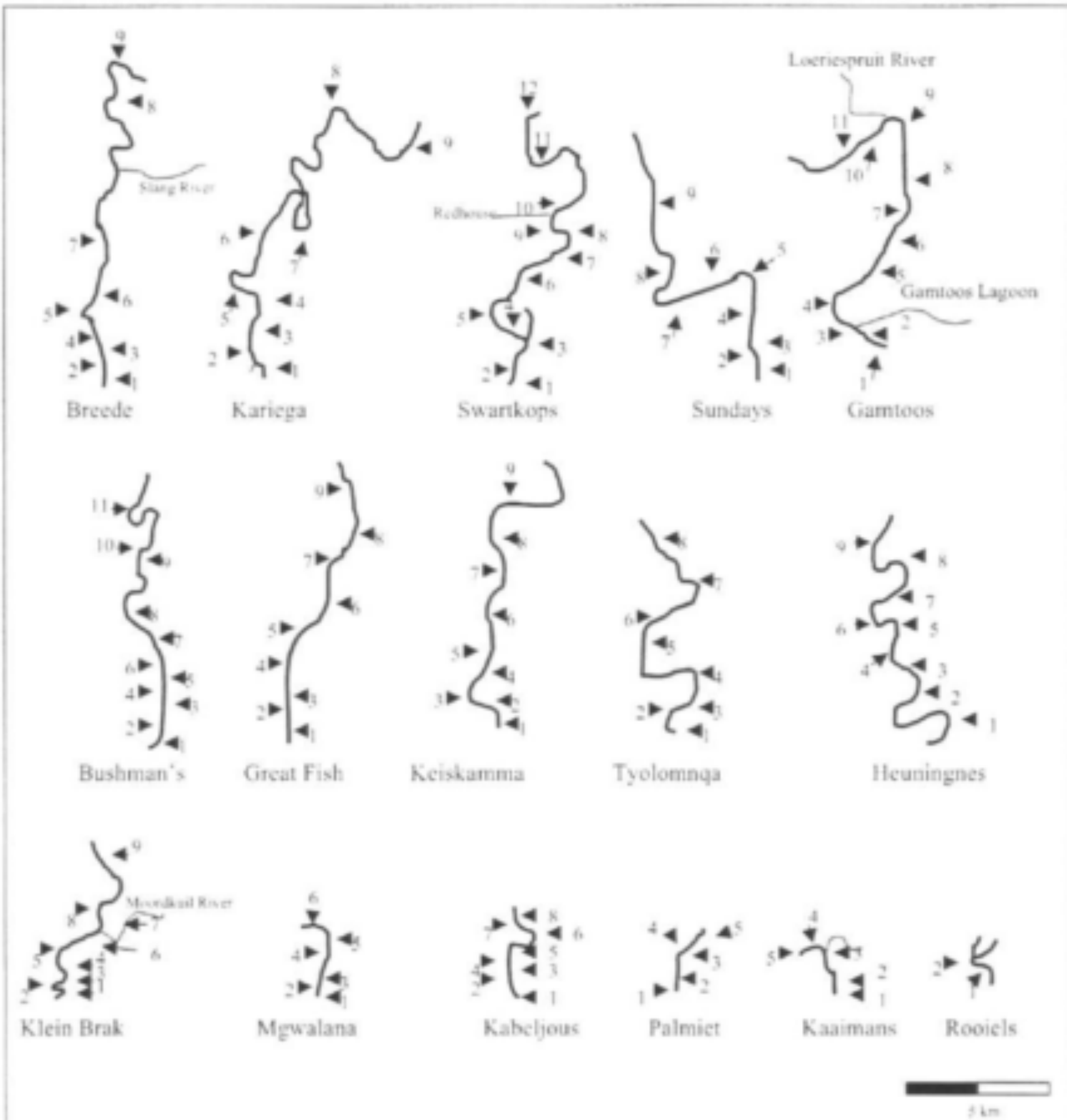


Figure 4.2. Maps of all estuaries investigated in this study with sampling sites indicated by arrows. The relative sizes of each estuary are also given in the map.

4.3 Methods

4.3.1 Invertebrate sampling

Core samples of invertebrate macrofauna were obtained from a total of 88 sites in 16 estuaries (Figure 2) during September and October 2002, using a nested sampling protocol that allowed for comparisons between estuaries and between sites within estuaries. In general, two to twelve sites were sampled per estuary; two transects ~30m apart within each site, and three tidal levels (high water mark, mid water mark, and low water mark) within each transect for a total of six core samples collected at each site. Sampling was carried out throughout the length of the estuary in which intertidal areas were found. In the field, salinity measurements, changes in sediment type and vegetation patterns were used to define the reaches within an estuary (Teske & Wooldridge 2001). The lower reaches were characterised by high salinity and coarse grain sands, the middle reaches were typically a mix of sand and mud but in most cases were predominantly mud with salinity values between 15 and 25 ‰, and the upper reaches were also predominantly mud with low salinity (<15‰) and were marked by the presence of the common reed, *Phragmites australis*, a species that is intolerant of highly saline water. All estuaries were sampled during the heaviest tides to ensure that the intertidal zone was adequately sampled.

Each sample consisted of a sediment core of 270 mm depth and 180 mm diameter. Cores were sieved using a 0.5 mm mesh size and stored in plastic bags until they were sorted later in the day. Upon sorting, each sample was treated with rose bengal dye to stain the invertebrates, which were then removed and stored in collection bottles in a 10% formaldehyde solution. Care was taken with samples containing plant material to check for any animals that clung to the plant debris. Macroinvertebrates were identified to species level and counted using a binocular microscope in the laboratory. Previous data collected for South African intertidal and subtidal invertebrates sieved the samples using a 1.0 mm mesh size and although time efficient, retains a smaller proportion of species present. The retention efficiency for total biomass using a 1.0 mm mesh size is only 49% but is improved to 86% when using a 0.5 mm mesh size (Schlacher & Wooldridge 1996a).

The prawn species, *Upogebia africana* and *Callianassa kraussi*, burrow up to 1.0m in the mudflats and therefore could not be adequately captured by the core samples (Hanekom *et al.* 1988). Intertidal prawn abundance was thus quantified using 0.25 m^2 quadrats with twelve replicates per site. The quadrats were placed adjacent to the samples along the transects within each site. Within each quadrat, prawn holes were counted to estimate prawn density and care was taken in distinguishing prawn holes from other types of burrowing invertebrates such as pencil bait *Solen capensis* and blood worm *Arenicola loveni* (Zoutendyke & Bickerton 1988). No distinction was made between types of prawn holes as it was too difficult to distinguish between *Upogebia* and *Callianassa* holes with any degree of certainty in the field. A ratio of 1:1 was used for the number of holes to the number of prawns in the sediment as this was similar to the actual ratio of 1:1.05 determined by Clark (1998). This ratio was developed for *Callianassa* holes and thus could potentially underestimate the number of *Upogebia* since the ratio of prawns:holes is not well documented for *Upogebia*.

4.3.2 Assessment of sampling effort

Species effort curves were constructed to determine whether estuaries had been adequately sampled, and to investigate the minimimum level of sampling that would be required in order to adequately assess an estuary's conservation importance. Species effort curves were constructed for each estuary by randomly re-sampling all cores for 100 iterations. From this iterative process, the cumulative mean, minimum, and maximum number of species could be calculated for different levels of sampling effort (number of cores).

The data set summarising species captured per core was sub-sampled to determine how many species would be captured if a rapid survey was conducted instead of the comprehensive sampling effort used in this study. This rapid survey was done at three levels of sampling intensity, 9 cores per estuary, 18 cores per estuary, and 27 cores per estuary. For simulating this sampling exercise, one core was taken at each sampling site in the estuary starting at the mouth and moving up the estuary with each additional core. After reaching the top site in the estuary, another core was then taken at each site starting again at the mouth of the estuary and extending to the upper reaches. This was repeated until the level of sampling intensity or the maximum number of species was reached for each estuary.

4.3.3 Environmental Data

Data were analysed with respect to environmental variables at two separate scales: 1) sites within an estuary and 2) between estuaries.

At the site level, seven environmental variables were examined: total organic matter in the sediments, median particle size, a sorting coefficient, percent mud, presence or absence of *Zostera capensis*, distance from the mouth of the estuary, and salinity. Distance from the mouth was estimated using ortho-photographs (1:10 000) of each estuary. In the middle of the channel at each site, salinity was recorded from a boat using an optical refractometer at the time of macrofaunal sampling at the surface and at half meter intervals until the maximum depth was reached.

Two sediment samples were taken at each site. One sample was used to determine median particle size, the sorting coefficient, and percent mud. Mud fractions were separated from the coarse fraction by wet-sieving a weighed subsample using a 63 µm sieve. The remaining coarse fraction was placed in a pre-weighed beaker and dried at 110° C. The percent of mud in each sample was then calculated from the mass differences between the subsamples before and after sieving. The sand fraction was divided to obtain a statistically random split of about 3 grams for settling in a settling column which yielded the median particle size (expressed in phi (Φ) units to give md Φ) and the sorting coefficient (also in Φ units) (Boggs 1995). Both the percent mud, median particle size, and a sorting coefficient were included in the analysis because the median particle size and sorting coefficient were calculated for the sand fraction only, thus giving no indication of the quantity of mud in the sediments. The md and the sorting coefficient were both necessary to adequately describe the nature of the sand fraction in the sediments because the md Φ only yields the 50th percentile diameter of the sediments while the sorting coefficient describes the range of grain sizes found in the sediments. Teske & Wooldridge (2001) concluded that the type of sediment is a major determinant of subtidal invertebrate zonation patterns.

A second sediment sample was used to estimate total organic matter present. Each sample was dried for 24 hours at 110°C in a drying oven. After drying, the samples were placed in crucibles of known weight in order to get the dry weight of the sediments before ignition. The crucibles were then placed in a muffle furnace for 3 hours at 550°C. They were then removed from the furnace, placed in a desiccator, and weighed again to determine the amount of organic matter lost on ignition (Berglund 1986).

Ten environmental variables were used for comparisons between estuaries: water quality index, human disturbance index, mouth condition, estuary area and length, slope of the river, distance from Cape Point, median particle size (md Φ), mean percent mud, and mean annual runoff.

The water quality of each estuary was estimated using data from Harrison *et al.* (2000). This index has three principle components; suitability for aquatic life, suitability for human contact, and trophic status which together determine an estuary's water quality status. The suitability for human contact was not regarded as an important variable controlling macroinvertebrate distribution so was excluded and a water quality index (WQI) was developed for this study using the two remaining parameters. The suitability for aquatic life incorporates the dissolved oxygen which is essential to aquatic fauna, the oxygen absorbed which is a measure of organic loading, and the unionised ammonia, a known toxin to aquatic fauna. The trophic status component incorporates nitrate and ortho-phosphate concentration, which stimulate growth in aquatic plants. These parameters were combined with equal weight and a water quality score on a scale of 0 (poor quality) to 10 (excellent quality) was assigned to each estuary in the study.

A human disturbance index (HDI) was subjectively assigned to each estuary on a scale of 1 (no disturbance) to 5 (highly disturbed). The HDI gives an indication of the amount of habitat loss around the estuary. Values were assigned based on the number of houses adjacent to the estuary, the level of development and amount of farming around the estuary, the type and level of industries operating close to the estuary, the abundance of recreational boaters and fishermen, and the abundance of bait collectors in the intertidal areas. The Swartkops, for example, had the highest human disturbance (HDI = 4) as it was marked by several industries with effluent running directly into the estuary and a high abundance of fisherman and bait collectors. The Kaaimans estuary had the lowest human disturbance (HDI = 1) and was in a near pristine state with only a few houses along its banks.

Area and length for each estuary were taken from previously published data (Turpie *et al.* 2002). The slope of a river was taken from GIS data using the elevation at the source of the river and the length of the river. The distance from Cape Point was calculated from GIS data and was used as a variable to account for the subtropical subtraction effect (Whitfield 1994; Turpie *et al.* 2000; Awad *et al.* 2002). This effect represents a progressive loss of species richness and diversity as one moves West from the subtropical region towards Cape Point. Median particle size (md Φ) and mean percent mud in the estuary were taken from the site data mentioned above and a mean was calculated for each estuary. Mean annual runoff was taken from Harrison *et al.* (2000).

Whitfield's classification (1994) does not reveal the finer scale details of the differences between permanently open and temporarily closed estuaries. For this reason, estuaries were categorised according to their predominantly occurring mouth condition: 1 = closed, 2 = semi-closed and 3 = open. Estuaries were assigned to categories using historical data (Van Niekerk *et al.* 2002). A semi-closed state occurs when the mouth of an estuary has only a shallow, narrow opening allowing for a small outflow channel to sea (Van Niekerk *et al.* 2002). Semi-closed mouth states have only limited sea water intrusion, little to no tidal variation, and are characteristic of the smaller estuarine systems in South Africa, including the Rooiels, Palmiet, and Kaaimans estuaries. The Klein Brak is classified as temporarily open/closed, but its predominant mouth state is open, as it only closes once every two to three years. This estuary thus has a well developed intertidal community and is more akin to a permanently open system.

4.3.4 Analysis of within- and between-estuary patterns

Variation in macroinvertebrate assemblages associated with different sites and in different estuaries was assessed using multivariate analyses run on the PRIMER software package (Clarke & Gorley 2001). Similarity matrices relating pairs of sites and estuaries were calculated for macrofauna using the Bray-Curtis similarity coefficient and then analysed using non-metric multidimensional scaling (MDS). Species data were double root transformed before analysis to scale down the importance of dominant species while retaining the information about rare species. MDS plots were produced for all estuaries to compare the sites within an estuary, except the Rooiels estuary where only two sites were sampled.

A similarity matrix and MDS plots were constructed for all the estuaries to identify clusters between the different estuaries. The data set describing total density of species in each estuary was first refined to exclude the rarer species (Species<1% of total abundance) as recommended by Clarke & Warwick (1994). This refinement retains the 50 to 60 species with the highest total abundance across all samples resulting in a more interpretable ordination plot. When examining the faunal patterns within each estuary, the exclusion of rare species was not necessary.

Similarity matrices were calculated and principle components analysis (PCA) were performed for the environmental data as recommended by Clarke & Gorley (2001). The BIOENV procedure using Spearman rank coefficients was used to determine which combination of physical variables correlated best with patterns from the biotic community assemblages. When performing the BIOENV analysis, environmental variables were first tested for auto-correlation using Draftsman plots. Any variables that were found to be significantly auto-correlated ($r_s > 0.95$) were omitted to leave only one variable. The one remaining variable can be used as a substitute for the other correlated variables without effective loss of information. A SIMPER ("similarity percentages") routine was used to identify which taxa were responsible for making the greatest contribution to the differences between clusters of estuaries identified in the MDS plots (Clarke & Warwick 1994).

4.4 Results

4.4.1 Physical characteristics of the estuaries

Broadscale characteristics of the 16 estuaries are summarised in Table 4.1. Most of the estuaries are permanently open, though two of these (Palmiet and Kaaimans) have a predominantly semi-closed mouth condition. Four of the sixteen are classified as temporarily open/closed, though one of these (Klein Brak) has a predominantly open mouth. The sizes of the estuaries studied varied from 8 to 499 ha. The estuaries were fed by rivers of 0.6 to 25 km length and ranged in gradient from extremely steep (1:11) to extremely flat (1: 588). Average muddiness varied greatly between systems, but there was less variation in mean particle size (Table 4.1). Physical characteristics also varied substantially along each estuary. Although most estuaries followed similar general trends (Figure 4.3), there are differences between the systems.

Table 4.1. Summary of the general environmental characteristics of each estuary (listed from West to East).

ESTUARY	Type	Predominant Mouth Condition	Area (ha)	Length (km)	Slope	Km from Cape Point	Mean % Mud	MdΦ	WQI	HDI
Rooiels	T	2	11	0.6	1:11	31	0.7	2.10	7.57	1
Palmiet	P	2	33	1.6	1:63	46	1.4	1.24	9.14	1
Heuningnes	P	3	173	11.4	1:200	154	3.4	2.28	7.57	2
Breede	P	3	463	25.0	1:256	217	21.5	2.67	8.86	3
Klein Brak	T	3	96	5.1	1:192	338	10.8	1.91	8.57	3
Kaaimans	P	2	8	1.5	1:20	378	19.3	2.33	9.29	1
Kabeljous	T	1	134	2.4	1:71	596	7.9	1.71	6.29	2
Gamtoos	P	3	490	22.0	1:125	603	27.3	2.56	5.86	3
Swartkops	P	3	499	14.9	1:102	662	8.1	2.27	8.14	4
Sundays	P	3	173	15.4	1:323	682	26.6	2.94	6.57	3
Bushmans	P	3	213	15.1	1:588	759	39.3	2.22	7.57	2
Kariega	P	3	198	15.7	1:213	761	25.4	3.59	6.43	2
Great Fish	P	3	366	11.2	1:323	809	21.5	2.47	8.29	3
Mgwalana	T	1	124	2.6	1:152	825	31.8	2.52	7.71	1
Keiskamma	P	3	494	7.3	1:233	844	51.8	2.09	7.00	4
Tyolomnqa	P	3	107	6.1	1:145	858	25.4	3.59	8.71	4

Type = Whitfield's Classification (1994): P. = permanently Open Estuary, T. = temporarily open estuary; Mouth Condition (Van Niekerk *et al.* 2002): 1= closed, 2= semi-closed, 3= open; Water Quality Index (WQI) (from Harrison *et al.* 2000): 1=poor, 10=excellent; Human Disturbance Index (HDI): 1=undisturbed, 5=highly disturbed.

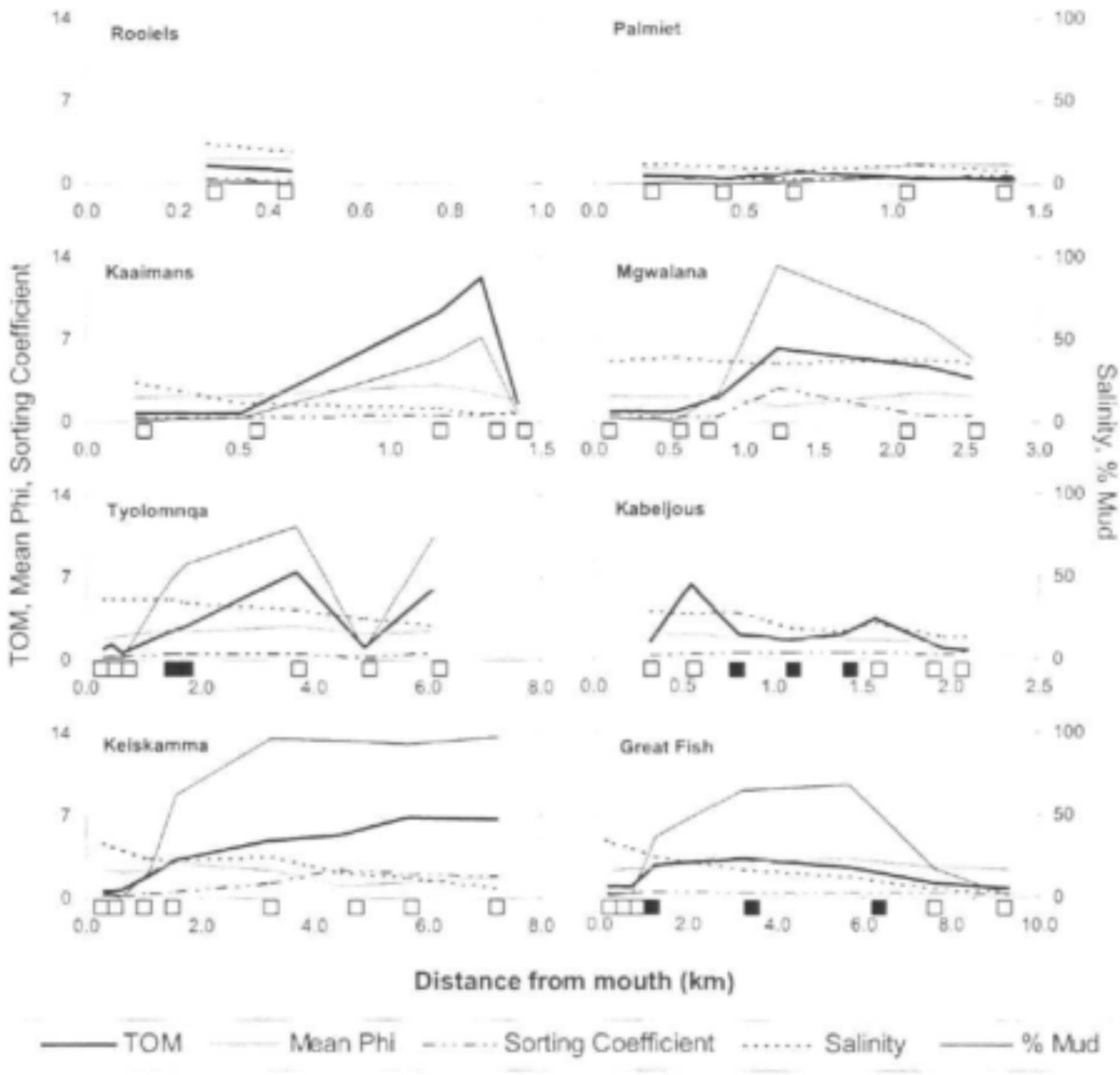


Figure 4.3. Physical characterstics within the different estuaries in the study area. Estuaries for which salinity data were not measured are marked with asterisks. Presence of *Zostera* is indicated by the solid square on the X-axis.

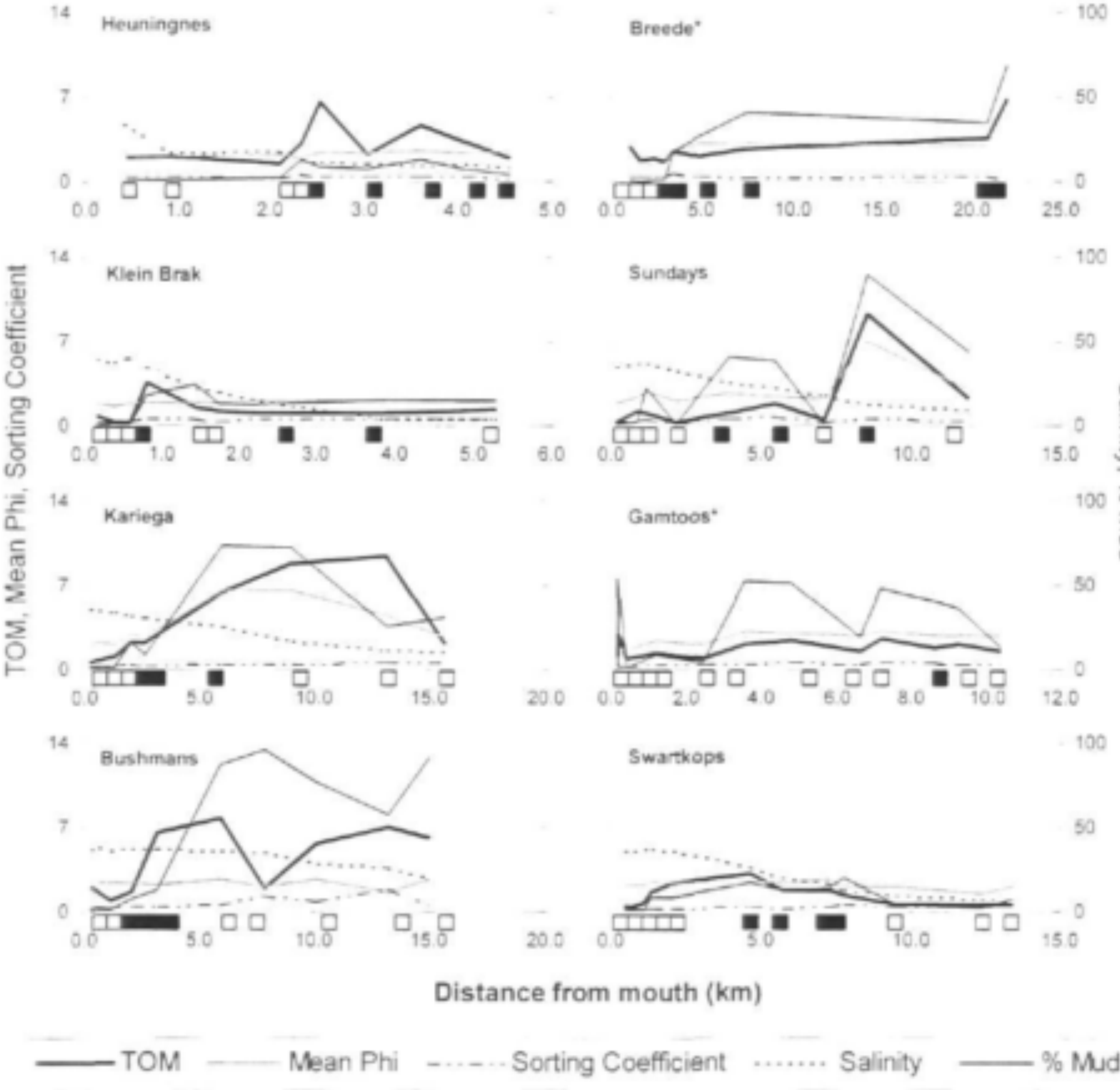


Figure 4.3 continued.

4.4.2 Patterns of species richness and abundance

A total of 9,064 individuals belonging to 97 invertebrate taxa were recorded from sixteen estuaries during the study (Table 4.2). Crustaceans (38 species) were the richest taxonomic group, followed by polychaetes (23 species) and molluscs (23 species).

Few species were cosmopolitan, most having been collected at only one (40%) or two estuaries (57%). Most of the common species (e.g. *Ceratonereis erythraeensis*, *Cirolana fluviatilis*, *Grandidierella lignorum*, and *Corophium triaenonyx*) were found in all reaches of the estuaries sampled and there were no distinct cut-offs for their distribution. There were a few common species found exclusively in the lower sandy reaches of the estuaries sampled. *Pontogeloides latipes* and *Urothoe pinnata* were found in the lower sites of twelve and eleven of the estuaries studied, respectively. *Scololepsis squamata* and *Eurydice longicornis* were also found exclusively in the lower sandy sites of seven and five estuaries, respectively. This is consistent with their preferred habitats of high salinity and sandy substrates near the estuary mouth (Branch *et al.* 1994). By contrast, *Dendronereis arborifera*, *Cyathura estuaria*, and *Paratylodiplax* spp. were found mainly in the middle and upper reaches of five, thirteen, and twelve of the estuaries, respectively. Species common in the upper muddy reaches were those known to prefer *Zostera* beds or mud with low salinity (Branch *et al.* 1994).

Species richness per estuary ranged from 6 in the Rooiels to 33 for the Bushmans. Although species richness tended to be higher in larger and longer estuaries, the only significant correlation was with with river slope (Figure 4.4).

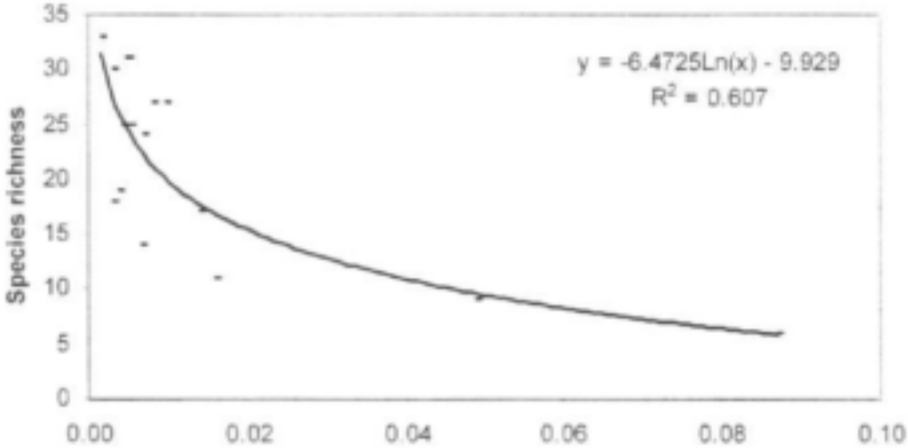


Figure 4.4. Relationship between intertidal invertebrate species richness and river slope in 16 estuaries

Table 4.2. List of all taxa found in the Warm Temperate Region. Numbers are given as density (m^{-2}) within each estuary

	Rooiels	Palmiet	Heuningnes	Breede	Klein Brak	Kaaimans	Kabeljous	Gamtoos	Swartkops	Sundays	Bushmans	Kariega	Mgwalana	Great Fish	Keiskamma	Tyolomnqa
Nemertea																
Cerebratulus sp.	--	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--
Gorgonorhynchus sp.	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
Polychaeta																
Unidentified Nemertean	--	--	--	--	--	--	--	2	--	1	--	--	--	--	--	3
Aonides oxycephala	--	--	--	--	--	--	--	--	--	--	3	--	--	--	--	--
Arenicola loveni	--	--	--	--	--	--	--	--	1	1	--	--	--	--	--	--
Capitella capitata	--	--	4	--	--	--	83	--	--	--	1	--	6	--	--	1
Capitellidae sp	--	--	--	--	--	--	--	1	3	--	--	3	--	--	--	--
Ceratonereis erythraeensis	40	72	1	37	150	5	2	23	41	--	42	21	--	10	82	171
Ceratonereis keiskamma	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5
Ceratonereis sp.	--	404	--	--	4	--	175	30	106	33	--	1	--	--	4	--
Dendronereis arborifera	--	--	--	--	--	--	--	1	--	--	5	10	63	--	--	45
Glycera sp.	--	--	--	7	--	--	--	--	--	--	--	--	--	--	--	--
Lumbrinereis brevicirra	--	--	3	--	4	--	--	--	1	--	--	--	--	--	--	--
Lumbrinereis tetraura	--	--	--	--	--	--	--	--	--	--	1	--	1	--	--	--
Magelona cincta	--	--	--	--	--	--	397	3	--	--	--	1	--	--	--	--
Nephtys capensis	--	--	4	1	--	--	--	--	--	--	--	2	--	--	--	--
Nephtys hombergi	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--
Nephtys sp.	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Nereid sp	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Notomastus sp.	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Pectinaria capensis	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Prionospio pinnata	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--
Scololepsis squamata	--	--	4	--	--	--	--	2	1	--	1	2	--	--	1	3
Unidentified Polychaeta A	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
Unidentified Polychaeta B	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Unidentified Polychaeta C	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--

	Rooiels	Palmiet	Heuningnes	Breede	Klein Brak	Kaaimans	Kabeljous	Gamtoos	Swartkops	Sundays	Bushmans	Kariega	Mgwalana	Great Fish	Keiskamma	Tyolomnqa
Oligochaeta																
Unidentified Oligochaeta	--	--	--	14	--	--	--	--	--	--	--	--	--	2	--	--
Copepoda																
Copepoda sp.	--	--	3	--	--	--	--	1	1	1	--	--	1	--	--	1
Cumacea																
Iphinoe truncata	--	--	--	--	3	--	--	--	--	--	--	--	--	--	--	--
Tanaidacea																
Apseudes digitalis	--	11	--	124	5	17	--	20	1	--	140	4	148	--	1045	75
Isopoda																
Cirolana fluviatilis	--	--	--	--	--	1	1	3	3	--	--	3	1	--	--	--
Cirolana hirtipes	--	--	--	--	--	--	--	--	--	--	--	--	1	--	1	1
Cyathura estuaria	30	63	--	9	2	7	32	5	--	--	68	47	21	1	91	37
Eurydice longicornis	--	--	--	--	--	--	--	6	2	1	1	--	--	5	--	--
Exosphaeroma hylecoetes	--	--	1	--	1	--	1	--	--	--	1	2	--	--	--	--
Paridotea ungulata	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--
Pontogeloides latipes	40	--	4	--	--	44	14	1	3	3	15	6	12	31	13	40
Amphipoda																
Afrochiltonia capensis	--	--	--	--	--	--	111	--	--	1	--	--	--	--	--	--
Amphipoda sp.	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Corophium triaenonyx	--	6	--	1	10	--	4	1	--	--	--	1	--	--	--	--
Corophium sp.	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	1
Grandidierella chelata	--	--	--	--	--	--	--	--	--	--	22	--	68	2	2	--
Grandidierella lignorum	--	467	4	7	39	--	--	8	1	7	--	8	--	--	1	--
Grandidierella lutosa	--	--	--	--	--	--	--	--	--	--	--	--	--	23	--	--
Grandidierella sp.	7	74	--	5	33	8	--	--	--	--	--	--	--	--	2	--
Melita zeylanica	--	--	6	--	2	--	20	--	2	--	--	1	1	--	4	2
Orchestia rectipalma	3	--	--	--	1	17	49	--	--	--	--	--	--	--	--	--
Orchestia sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	11	--
Urothoe elegans	--	--	--	--	--	--	7	--	--	--	2	--	3	--	1	--
Urothoe pinnata	--	--	39	--	41	24	4	8	18	22	445	21	187	168	170	13

	Rooiels	Palmiet	Heuningnes	Breede	Klein Brak	Kaaimans	Kabeljous	Gamtoos	Swartkops	Sundays	Bushmans	Kariega	Mgwalana	Great Fish	Keiskamma	Tyolomnqa
Mysidacea																
Gastrosaccus brevifissura	--	--	--	--	--	--	--	3	--	--	--	1	--	--	--	--
Gastrosaccus psammodytes	--	--	--	--	--	--	--	--	--	--	--	--	--	3	1	--
Mesopodopsis slabberi	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--
Decapoda																
Alpheus crassimanus	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--
Bataeus jucundus	--	--	3	10	10	--	--	1	3	3	--	1	1	--	--	--
Palaemon pacificus	--	--	--	--	1	--	--	--	--	1	11	2	1	--	--	--
Anomura																
Prawns	10	166	50	284	97	18	48	86	169	86	59	32	196	89	82	73
Diogenes brevirostris	--	--	18	3	--	--	--	--	6	1	1	4	--	--	--	--
Brachyura																
Dotilla fenestrata	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--
Hymenosoma orbiculare	--	--	1	--	1	--	2	--	--	--	8	2	2	1	--	1
Paratylodiplax algoense	--	--	26	1	1	--	--	--	1	12	1	2	1	11	35	11
Paratylodiplax edwardsii	--	--	54	4	6	--	--	4	19	--	23	8	52	9	20	39
Paratylodiplax sp	--	5	--	--	--	--	--	--	--	--	--	11	--	--	--	--
Sesarma catenata	--	5	--	--	--	--	--	--	--	--	1	--	--	--	--	--
Thaumastoplax spiralis	--	--	4	2	--	--	--	2	9	4	1	--	--	--	1	2
Mollusca																
Anodonta edentula	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--
Arcuatula capensis	--	--	--	--	--	--	--	--	--	--	3	3	--	--	--	--
Assiminea globulus	--	--	--	1	--	--	--	--	--	--	--	19	--	--	--	--
Assiminea ovata	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
Bivalve sp.	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Brachidontes virgiliae	--	--	--	--	--	--	--	--	--	--	13	--	--	--	--	--
Eumarcia paupercula	--	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--
Haminoea alfredensis	--	--	7	--	--	--	--	--	--	--	--	--	--	--	--	--
Loripes clausus	--	--	1	--	3	--	--	--	--	1	2	--	--	--	--	--
Loripes sp.	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--

	Rooiels	Palmiet	Heuningnes	Breede	Klein Brak	Kaaimans	Kabeljous	Gamtoos	Swartkops	Sundays	Bushmans	Kariega	Mgwalana	Great Fish	Keiskamma	Tyolomnqa
Macoma litoralis	--	--	1	--	1	--	46	3	9	--	9	--	17	--	--	--
Nassarius kraussianus	--	--	--	--	--	--	--	--	--	--	6	28	22	--	--	7
Natica genuana	--	--	2	--	--	--	--	--	--	--	--	12	1	--	--	--
Natica gualteriana	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8	--
Natica sp	--	--	3	--	--	--	--	--	1	--	--	--	--	--	--	--
Natica tecta	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--
Octopus granulatus	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
Psammotellina capensis	--	--	--	--	--	--	--	--	--	--	--	--	1	--	2	1
Sanginolaria capensis	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--
Solen capensis	--	--	--	--	--	--	--	2	--	--	1	--	6	--	--	7
Unidentified mollusc 1	--	--	--	--	--	--	--	--	--	--	9	--	17	--	--	--
Unidentified mollusc 2	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
Unidentified mollusc 3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	12	--
Inescta																
Chironomid larvae	--	22	--	--	--	--	--	1	3	4	--	--	--	--	--	--
Dolichopodidae	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--
Insecta pupae	--	--	--	--	--	--	--	--	--	3	--	--	--	--	--	--
Stratiomyidae	--	--	--	--	--	--	--	--	--	--	8	--	1	3	11	2
Xanthocanace	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--
Unidentified Insecta 1	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--
Unidentified Insecta 2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
Unidentified Insecta 3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--
Total number of taxa	6	11	31	19	25	9	17	27	27	18	33	31	30	14	25	24
Average individuals per m^2	129	1296	251	513	421	141	996	220	405	184	903	261	837	359	1606	541

Permanently open systems contained an average of 23.8 ± 7.9 species (n = 12), compared with 15.5 ± 7.9 species for temporarily open/closed systems. When compared in terms of mouth condition, estuaries whose predominant mouth state was open had the highest species richness, and those with semiclosed mouths had the lowest species richness (Figure 4.5)

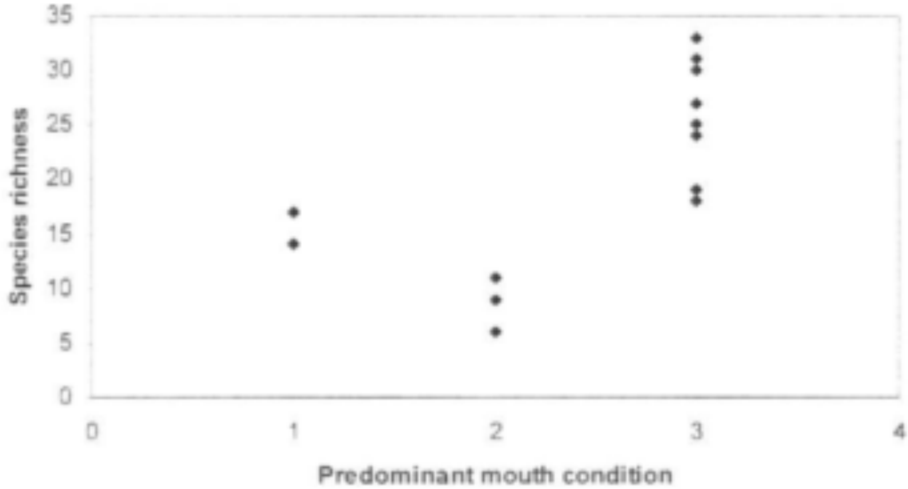


Figure 4.5. Species richness in relation to predominant mouth condition: 1 = closed, 2 = semi-closed, 3 = open.

The average overall densities of intertidal invertebrates ranged from 129 per m^2 in the Rooiels to 1606 per m^2 in the Keiskamma. There was no relationship between species richness and invertebrate density. Some estuaries had low species richness and abundance (e.g. the Rooiels), some had low richness and high abundance (e.g. Palmiet, in which 79% of numbers are made up of the polychaete *Ceratonereis* spp., the amphipod *Grandidierella lignorum*, and the sand prawn *Callianassa kraussi*), some had high richness and abundance (e.g. Keiskamma), and some had high richness and low abundance (e.g. Kariega, Heuningnes).

Within estuaries, species richness and overall abundance varied along the estuary. Both decreased with increasing distance from the mouth in the Heuningnes and Kaaimans estuaries. However, in most estuaries (the Palmiet, Breede, Klein Brak, Kabeljous, Gamtoos, Swartkops, Bushmans, Kariega, Mgwalana, Tyolomnqa and Keiskamma), species richness and total number of individuals were highest in the middle to upper reaches. Species richness and abundance were uniformly distributed in the Sundays estuary. The

Great Fish was also peculiar in that it was the only estuary where the upper sites had lower species richness than the lower sites.

Species richness was significantly positively correlated with abundance within ten of the 16 estuaries, with the strongest correlations in the Tyolomnqa and Heuningnes estuaries (Figure 4.6). Such relationships were not found in the Kaaimans, Swartkops, Sundays or Bushmans, and were only weakly positive in the Mgwalana and Keiskamma estuaries. Neither species richness nor abundance was consistently correlated with any of the physical variables within estuaries.

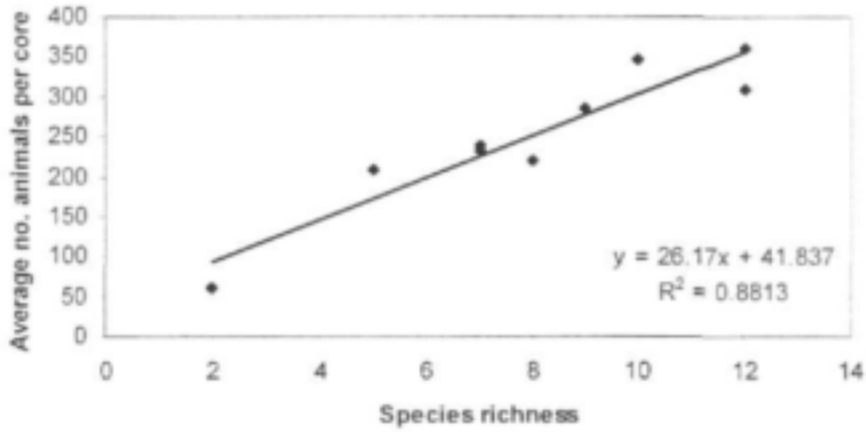


Figure 4.6. Average number of invertebrates per core for each site versus total number of species recorded at that site in the Heuningnes estuary.

4.4.3 Determinants of community structure within estuaries

The ordination plots of all estuaries are depicted in Figure 4.7. The stress statistics associated with these plots remained low across all estuaries ranging from 0 in the Kaaimans and Palmiet estuaries to 0.09 in the Gamtoos estuaries suggesting excellent two-dimensional representation of the results. There were pronounced differences in patterns between estuaries west and east of the Sundays. In the western estuaries, there was a gradual cline among species assemblages from the mouth to the upper reaches, wheras in the eastern estuaries, sites were separated into two distinct clusters.

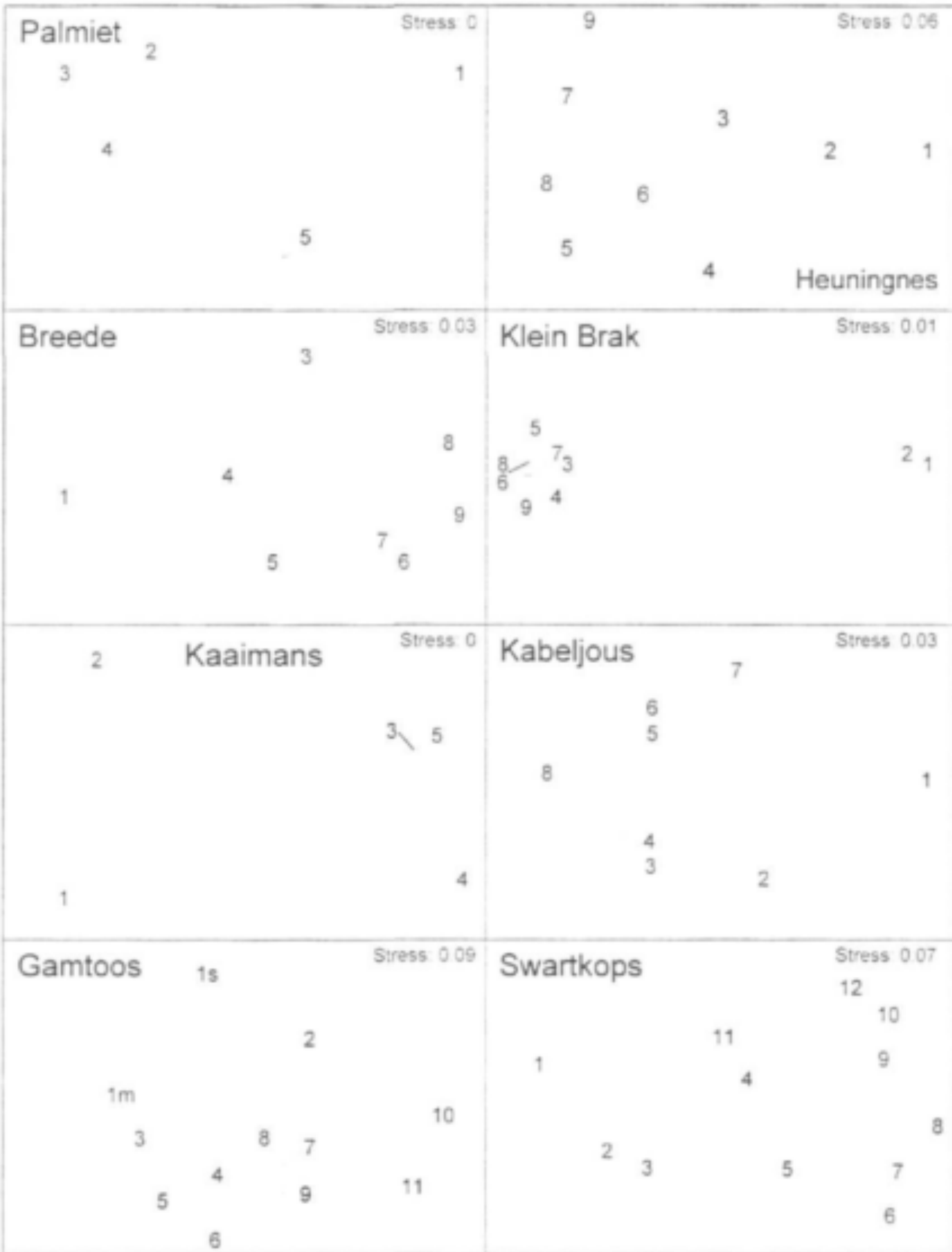


Figure 4.7. MDS ordination plots for each estuary. The sizes of the circles are scaled according to the percentage mud in the sediment. Labels indicate the location of each site within the estuary with site 1 at the mouth. No individuals were found in the cores or quadrats for Site 2 in the Breede estuary so it was omitted from the MDS plot.

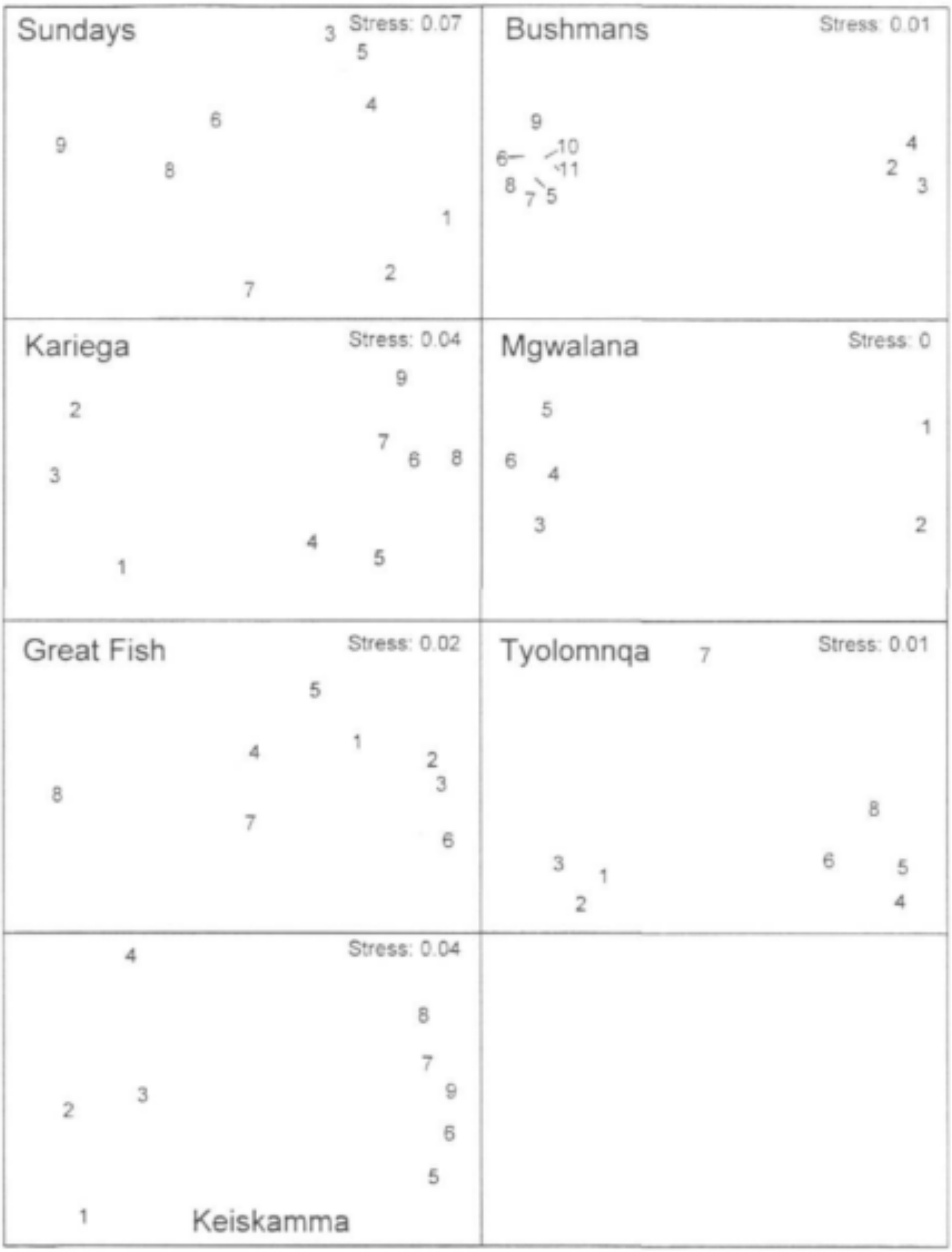


Figure 4.7 continued.

In general, patterns appeared to be strongly related to the percentage mud in the sediments (Figure 4.7), with sandy sites supporting different communities to muddier sites.

The results from the BIOENV analysis of the environmental variables affecting the biotic patterns within each estuary are summarised in Table 4.3. Intertidal macrofaunal patterns were influenced by a number of environmental variables. However, the variables and strength of the correlation influencing distribution patterns varied greatly between estuaries. In general, community assemblages were controlled principally by distance from mouth, quantity of organic matter in the sediments, percent mud, and median particle size (Md Φ) (Table 4.3). In the Gamtoos, total organic matter was excluded because it was significantly auto-correlated with percentage mud. The presence or absence of Zostera was excluded in the Great Fish due to its auto-correlation with total organic matter and percentage mud, and in the Breede, Md Φ was correlated with percentage mud. Percentage mud was exluded in the Kaaimans because of its correlation with total organic matter.

Table 4.3. Summary of the results for the BIOENV procedure for environmental variables affecting faunal patterns within estuaries. A dash indicates variables not included due to autocorrelation with other variables.

Estuary	Km fr mouth	Salinity	TOM	Md Φ	Sort coeff	Zostera	% mud	R_s	P
Palmiet	x	x						0.26	n.s.
Heuningnes	X			X			X	0.82	< 0.05
Breede	X					X	-	0.66	< 0.05
Klein Brak				X				0.85	< 0.05
Kaaimans	X	X	X				-	0.84	< 0.05
Kabeljous	X				X		X	0.81	< 0.05
Gamtoos	X		-				X	0.49	n.s.
Swartkops		X	X		X	X		0.66	< 0.05
Sundays	X							0.67	< 0.05
Bushmans	X		X					0.44	n.s.
Kariega					X			0.64	< 0.05
Great Fish	X				X	-		0.41	n.s.
Mgwalana	X		X					0.37	n.s.
Keiskamma			X					0.76	< 0.05
Tyolomnqa					X	X	X	0.66	< 0.05

4.4.4 Patterns of community structure among estuaries

The ordination plot incorporating all the estuaries is depicted in Figure 4.8. The stress statistics associated with the result was 0.16 for a two-dimensional plot and 0.06 for a three-dimensional plot. The three-dimensional plot provided additional clarity particularly when explaining the relatively high stress statistic associated with the two-dimensional plot. From the three-dimensional plot it was evident that some of the outliers, mainly the Kabeljous and to a lesser extent the Kaaimans, Rooiels and Palmiet, were depicted far from the two-dimensional plane thus accounting for the high stress statistic when displaying the MDS data in a two-dimensional plot. The two-dimensional plot was therefore considered to be adequate and the three-dimensional plot excellent in representing the data (Clarke 1993). In general, intertidal invertebrate communities appear to be more similar in estuaries which are predominantly or permanently open relative to those in estuaries which close more often (Figure 4.8). A similar result was obtained when data were analysed at the family level (Figure 4.9).

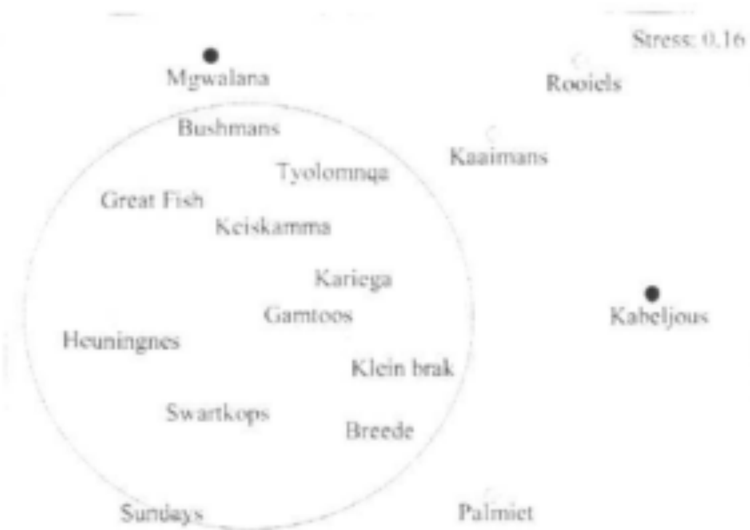


Figure 4.8. MDS Plots of all estuaries in the study. Circles represent predominant mouth condition: open, semi-closed (hashed), or closed (solid).

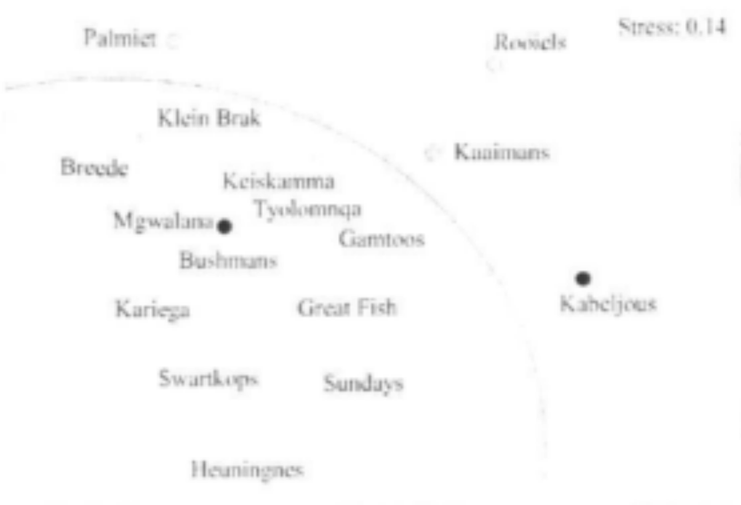


Figure 4.9. MDS plots using data aggregated to family level.

4.4.5 Species-effort curves and implications of sampling effort

Species effort curves calculated for each estuary sampled suggest that most of the diversity was captured in the sampling, since curves were flattening out for all systems (Figure 4.10).

Data were further analysed to investigate the level of sampling required to adequately reflect the species richness of an estuary, or at least the richness of estuaries relative to one another.

The results of subsampling of the data suggest that a sample of 27 cores per estuary would have captured over 100% of the species in eight of the estuaries and over 90% of the species in all other estuaries except for the Bushmans and the Heuningnes.

If one ranks estuaries in terms of their species richness on the basis of data obtained from different levels of sampling, sampling with 27 cores per estuary yields a ranking which has a very high correlation with that obtained by the sampling effort in this study($r^2 = 0.97$, $p<0.001$; Table 4.4). When only using 9 or 18 cores per estuary, several estuaries had equal rankings for richness.

Table 4.4. Spearman rank correlation coefficients between the different levels of sampling intensity

	9 Cores	18 Cores	27 Cores
18 Cores	0.71*		
27 Cores	0.66	0.96***	
All Cores	0.68	0.91***	0.97***

Significance levels: * p < 0.05, ** p < 0.01, *** p < 0.001.

Larger estuaries require more sampling effort than small systems, but required effort does not increase in proportion to size. For small estuaries (<40ha), 6-21 cores (0.77 cores per hectare) are required, medium-sized estuaries (40ha-200ha) require 20-27 cores (0.18 cores per hectare) and large estuaries (>200 ha) usually require 27 cores (0.06 cores per hectare). This amount of sampling effort ensures that approximately 90% of the species that would normally be captured are captured, if all cores in all estuaries were taken.

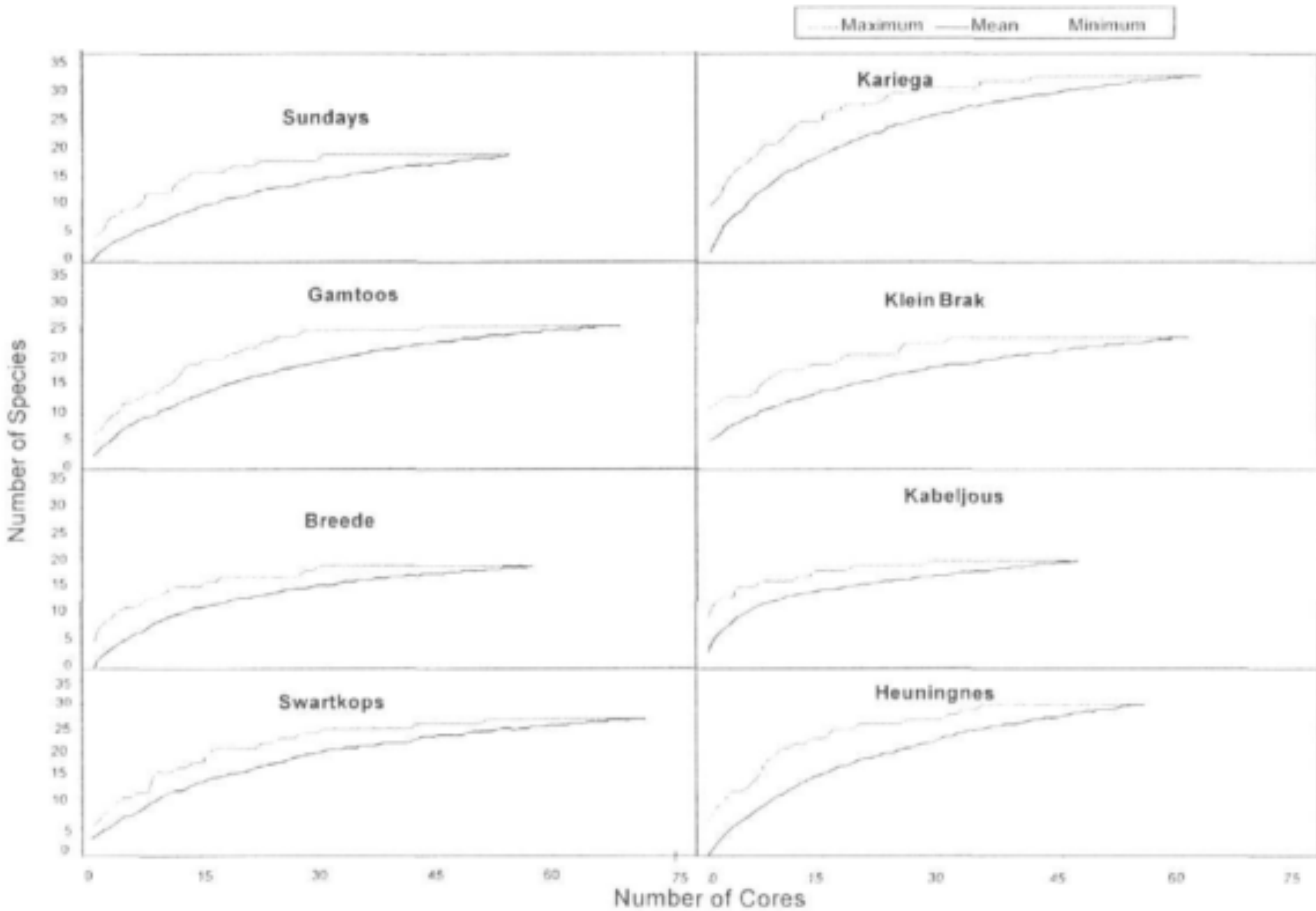
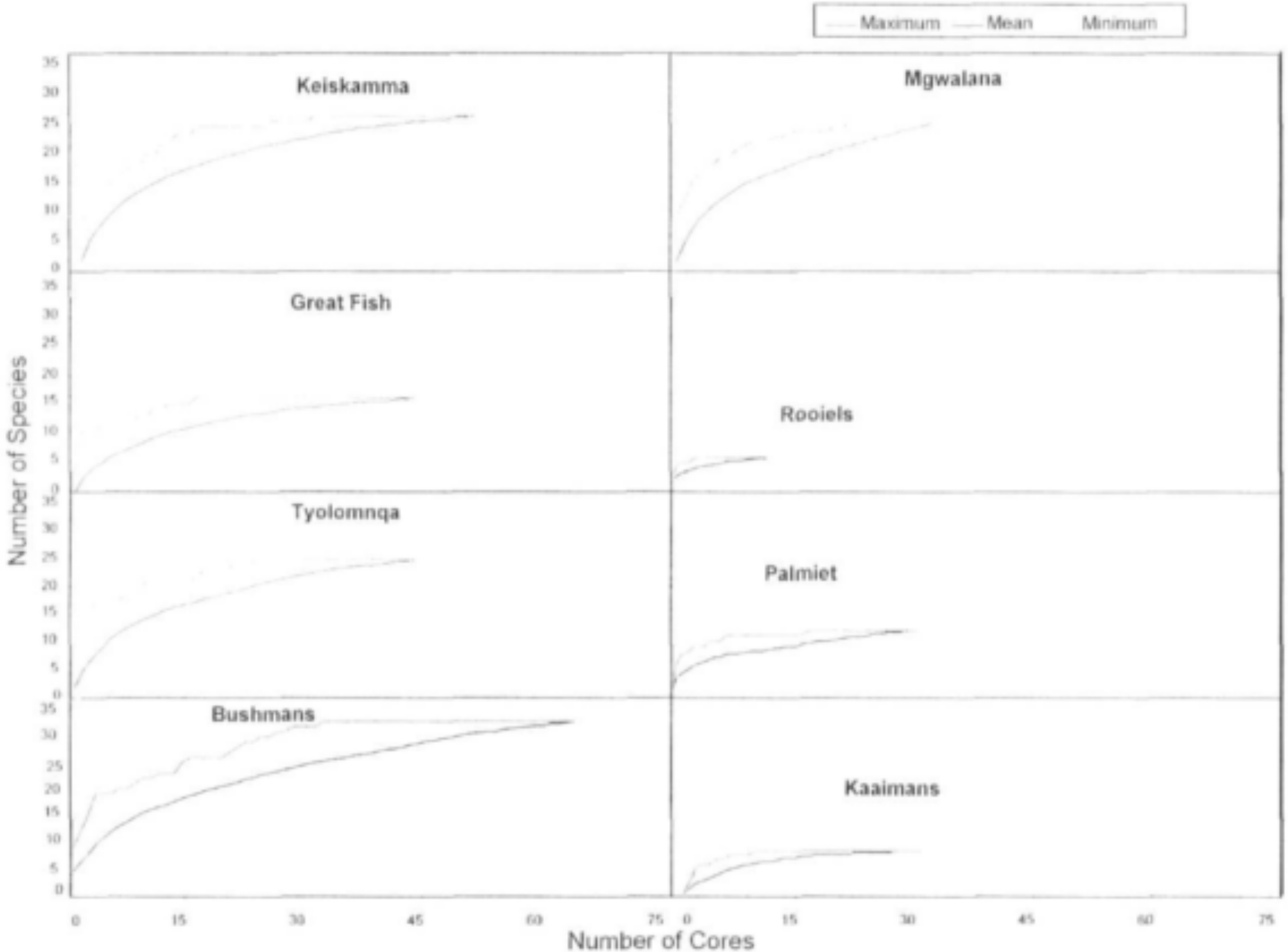


Figure 4.10. Species-effort curves for all the estuaries sampled during this study, showing the mean, maximum and minimum rate of accumulation of species with additional samples taken.



Maximum
Mean
Minimum
Keiskamma
Mgwalana
Great Fish
Rooiels
Tyolomnqa
Palmiet
Bushmans
Kaaimans
Number of Species
Number of Cores

Continued.

4.5 Discussion

4.5.1 Patterns of species richness, abundance and community structure within estuaries

Branch and Grindley (1979) found that species richness of intertidal invertebrates is typically highest at the mouth of estuaries, with a steady decline in numbers towards the head. Only the Heuningness and Kaaimans estuaries followed this pattern in this study. Most other estuaries had highest richness and abundance in the middle to upper raches. This is possibly linked to the greater diversity of available habitats in these reaches (Hodgson 1987), though it is probable that stable muddy banks could have provided the necessary conditions for supporting high diversity and abundance.

It is common to divide estuaries into the lower, middle and upper reaches in terms of their physical and biotic patterns (Raffaelli *et al.* 1991, Schumann *et al.* 1999). These reaches are defined mainly on the basis of differences in salinity (Schlacher & Wooldridge 1996b; Schumann *et al.* 1999). Fish and subtidal macrobenthic invertebrates are known to segregate in an estuary with respect to an axial salinity gradient and changes in sediments (Marais 1983, Bulger *et al.* 1993, Schalcher & Wooldridge 1996b). Schlacher & Wooldridge (1996b) identified four distinct subtidal macrobenthic faunal zones in the Gamtoos estuary, and Marais (1983) discerned top (upper and middle reaches) and bottom (lower reaches) sections of the estuary in terms of fish distributions. In this study, intertidal invertebrate communities in sandy mouth areas tended to be different from those in the rest of the estuary, particularly in the Klein Brak, Kariega, Bushmans, Mgwalana and Tyolomnqa and Keiskamma estuaries. The lower estuary supports a suite of species that are typically found in predominantly sandy, high salinity habitats. There was no discernable division between middle and upper reaches, however, but this is probably attributable to the fact that intertidal areas do not fully penetrate an estuary's upper reaches. No consistent relationships existed between intertidal invertebrate communities and physical characteristics such as salinity.

Above the mouth area, the ordination data also suggested a general cline in species assemblages along the length of estuaries. This concurs with a recent study of Tasmanian estuaries in which fauna did not separate into distinct clusters along the estuaries and had a high degree of overlap (Edgar *et al.* 1999). A study of four estuaries in New Zealand found that benthic macrofauna were distributed along a similar gradient with little of no grouping of sites within an estuary (Morrisey *et al.* 2003).

Teske & Wooldridge (2001) identified mud content as being the most important environmental variable responsible for subtidal macrofaunal patterns in 13 Eastern Cape estuaries. Maclachlan & Grindley (1974; focussing on anumurans and bivalves) also found substrate (together with competition) to be one of the main factors controlling macrofaunal communities in the Swartkops estuary, with salinity only playing a minor role. In this study, there were no strong trends in physical factors determining patterns of species richness or abundance, but community composition did appear to be strongly linked to mud content. BIOENV analysis identified the main determinants of intertidal community composition as distance from mouth and sediment characteristics, viz. quantity of organic matter in the sediments, percent mud, and median particle size (Md Φ). Various pairs of these characteristics were often correlated in estuaries, but there were no consistent patterns.

Salinity did not play an important role in determining intertidal community structure, though it is considered to be an important determinant of benthic invertebrate communities (e.g. Schlacher & Wooldridge 1996b). Salinity is a highly variable feature of estuarine systems and cannot accurately be captured during a single sampling trip. The state of the tide, coupled with rainfall events, can influence relative salinity values in an estuary at the time of sampling (Whitfield & Bruton 1989). Distance from mouth could be used as a proxy variable for the salinity gradient, since these two are often correlated. However, distance from mouth is also frequently correlated with changes in sediment characteristics. These factors probably explain why distance from mouth was found to be the strongest determinant of community structure in this study, rather than either salinity or a sediment characteristic. Morrisey *et al.* (2003) used the position of a site within an estuary as measured by the distance of the site from the mouth as a percentage of the total length of the estuary. This may provide a better surrogate for environmental factors that vary along an estuary and which are difficult to summarise in a single variable. The latter study found that percent sand, organic matter and distance from mouth were the main influences of benthic macrofauna in New Zealand estuaries. In contrast, salinity and tidal range were the most important factors influencing intertidal and subtidal macrobenthos in Tasmania, with mud content having only minor influence (Edgar *et al.* 1999). Another Tasmanian study identified salinity and seagrass biomass as the most important variables (Edgar & Barrett 2002). The presence or absence of *Zostera capensis* failed to contribute significantly in explaining macrofaunal patterns in this study.

4.5.2 Differences in species richness, abundance and community structure between estuaries

Differences in species richness between estuaries was not easily explained by any single factor such as size. Species richness tended to be highest in medium to large estuaries that are predominantly open, with the Bushmans estuary having the highest species richness. However, the best predictor of species richness was the slope of the river. Steep rivers are typically short and may lead to extreme scouring of estuaries during rainfall events. Longer, lower gradient rivers, on the other hand, attenuate the flooding effects of rainfall events, allowing for a more stable environment. In addition, these estuaries are likely to have longer water retention times, which allows for a more productive environment. These factors are likely to give rise to greater diversity and abundance of organisms. For example, the high species richness of the Kariega estuary has been explained in terms of its stable environmental conditions, low fine silt load from freshwater inputs, and stable salinity gradient (Hodgson 1987). The relatively stable environments associated with low-river-gradient estuaries probably also facilitates the development of *Zostera* beds, which increases the diversity of habitats available to intertidal invertebrates. The extensive *Zostera* beds in the Kariega, Bushmans and Swartkops estuaries probably contribute the high diversity of species in these estuaries. It is possible that biogeographical factors also play a role, given that Awad *et al.* (2002) documented a peak of species richness around Port Elizabeth for South African marine invertebrates, based on their coastal distributions.

The Great Fish, Sundays and Breede are relatively species poor, given the fact that these are large, permanently open systems. The Sundays and Fish receive additional freshwater input from the Upper Orange River inter-basin water transfer scheme. This drastically affects the intertidal fauna by promoting souring events in the estuary (Davies *et al.* 1992). Both estuaries also have high silt loads, which reduces species richness (De Villiers *et al.* 1999). In the case of the Breede, the relativley low species richness is partly attributable to its large tidal prism, leading to unstable sandy habitats near the mouth.

The high species richness in the Mgwalana is surprising given that it is temporarily open/closed, and is a relatively small estuary. The estuary was sampled during a brief open period, during which intertidal habitat was available. However, it is unlikely that a true intertidal invertebrate community could develop within the short open period, and the sample really reflected the subtidal macrobenthos.

Estuaries with the lowest species richness were semi-closed and closed systems (Palmiet, Kaaimans and Rooels) with steep river gradients. Low species richness in the Palmiet and Rooels estuaries has been attributed to high volume seasonal flooding and strong tidal inflow (Branch & Day 1984), creating highly disturbed conditions that only aloow a few highly competitive species to persist (Connell 1978, Huston 1979). Water quality is probably also an important factor. Unlike the Mgwalana, these are all estuaries that contain oligotrophic, tannin-coloured water in which estuarine productivity is limited by lack of nutrients and light penetration. The nature of this water is due to the *fynbos* vegetation of the catchments of these estuaries. Though many Western Cape rivers flow thorugh such areas, not all estuaries are 'black-water' estuaries. We suggest that this is probably because longer, shallow gradient rivers provide the opportunity for tannins to be removed from the water. Marine-tolerant species can thrive in the mouths of these estuaries, however, with very high densities recorded in the Palmiet. Branch & Day (1984) recorded high numbers of *Grandidierella*, *Cyathura* and *Ceratonereis* subtidally in the Palmiet, and this study found these species to be abundant in the intertidal zone as well.

Mouth condition was an important determinant of differences in species richness between estuaries. Low species diversity is commonly associated with closed estuaries in South Africa and Australia (Branch & Day 1984; Platell & Potter 1996). Indeed, 74 species occur in permanently open estuaries that are not found in temporarily open/closed systems. Several species of decapods are known to have an obligate marine larval phase (Wooldridge 1991, Pereyra Lago 1993), and thus cannot survive for long periods in estuaries with insufficient connection to the sea. There is little data on the larval biology of several estuarine polycheaetes and bivalves, but their absence from closed systems suggests that they may also have an obligate marine larval phase (De Villiers *et al.* 1999). Multivariate analyses showed that the faunal communities of the Rooiels, Palmiet, Kabeljous and Kaaimans estuaries were distinctly different from the other estuaries sampled, with the Kabeljous being most distinct. The Kablejous was the only system closed for most of the year. For parts of the year, the Rooiels, Palmiet and Kaaimans have a semi-closed mouth state, in which there is only a narrow outflow channel to the sea (van Niekerk *et al.* 2002). None of these estuaries support true intertidal communities, and the sampling effectively captured the subtidal community that was temporarily exposed. The relatively large Mgwalana estuary appeared to have greater affinity to permanently open estuaries in terms of its invertebrate community. Unlike the other temporarily open/closed estuaries, this system was hypersaline, with salinities of up to 36 ppt in the upper estuaries.

4.5.3 Sampling effort

The comprehensive sampling approach taken in this study appears to have paid off in terms of achieving representivity of estuarine taxa. It was assumed that if species were well sampled, then the community structure was also relatively well sampled. However, it should be noted that some of the smallest animals might have been under represented due to the fact that animals were picked from samples without the aid of a microscope.

Subsampling of the data suggested that if the purpose of sampling was to ascertain the relative rankings of different estuaries in terms of their species richness, then this could be achieved with far fewer samples.

4.6 Conclusions

Estuarine intertidal invertebrate community structure did not relate strongly to any single or group or environmental variables, and appeared to be influenced by a number of factors. This was the case when differences were examined both within and between estuaries. Within estuaries, muddiness appeared to play an important role, with distinct communities in very sandy areas, but other influencing factors ruled out strong correlations within or between estuaries. It could be concluded that communities within individual estuaries are distinct, and cannot be accurately predicted on the basis of simple environmental measures. Indeed, a large proportion of species recorded in the study were only present in one or two of the estuaries sampled.

Invertebrate abundance appeared to be influenced by multiple factors and was not strongly predictable. Species richness per estuary was perhaps the most easily predictable attribute, being strongly correlated with the slope of the river, and being related to estuary mouth condition.

These findings have important implications for assessing the conservation importance of estuaries where empirical data are lacking. It suggests that conservation importance indices should be based on relatively simple measure of species richness, with the measures for all unsampled estuaries being obtained by predictive models, or by rapid sampling of up to 27 cores per estuary. The best approach will depend on the accuracy of the predictive models obtained for all invertebrates.

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5. PREDICTING INVERTEBRATE SPECIES RICHNESS ON THE BASIS OF BROADSCALE ESTUARY CHARACTERISTICS

Jane Turpie, Barry Clark & Conrad Savy

5.1 Introduction

Determination of the relative conservation importance of different South African estuaries in terms of their invertebrate communities has been hampered by a lack of data, with only a small percentage of estuaries having been sampled. The use of distribution as surrogate presence-absence data for estuarine invertebrates, which has been employed as an interim measure (Turpie *et al.* 2002), is considered inadequate. One possible way of solving the problem of a lack of data is to predict the importance of different estuaries based on what is known about a few. This study investigates the feasibility of such an approach.

Previous studies (e.g. Teske & Wooldridge 2001, this study) have provided some insight into the determinants of estuarine invertebrate community structure both within and among different estuaries, although these studies have concentrated on benthic invertebrates only, and do not extend to planktonic communities. These studies have focused on investigating the factors influencing species richness and community patterns based on environmental variables measured explicitly for this purpose (e.g. salinity, sediment particle size). The choice of explanatory variables has included variables for which information would not be readily available for other estuaries. The aim of this study was to develop a predictive model for invertebrate species richness using variables that are readily available for most South African estuaries.

The key questions addressed by this study were as follows:

1. To what extent do invertebrate communities within intertidal, subtidal and planktonic habits overlap in composition
2. Are there any correlations between species richness of intertidal, subtidal and planktonic invertebrate communities in estuaries
3. Could one group of invertebrates provide an indicator of overall species richness?
4. What are the main determinants of estuarine invertebrate species richness for intertidal, subtidal and planktonic communities separately and together?
5. Can invertebrate species richness be predicted using broadscale characteristics of estuaries for which data are easily obtainable at a national level?

6. Is this a viable approach for estimating the importance of estuaries in terms of invertebrate communities in the absence of sufficient empirical data?

5.2 Methods

5.2.1 Overall approach

All available data on the species and densities of invertebrates recorded in South African estuaries were collated. Effort was focussed on the most recent published data (subsequent to 1980). Data were recorded in terms of presence-absence records, or as the average densities of animals per m^2 (for benthic invertebrates) or per m^3 (for planktonic invertebrates). Where possible, this data was separated by habitat into intertidal benthic, subtidal benthic and planktonic invertebrates. For benthos, only macrofauna > 0.5mm were considered.

Due to the limited availability of existing data, this study concentrated on the Warm Temperate region (from Cape Point to the Mbashe estuary), although broader analyses were initially attempted.

5.2.2 Habitat-based comparisons

Data sets were analysed to investigate the relative contribution of different components of the estuarine invertebrate fauna (planktonic, subtidal benthic and intertidal benthic) to overall invertebrate diversity, the extent of overlap between these communities, and whether there were strong enough correlations between them to use one community as a surrogate. These analyses were performed since more data were available for some groups than for others, and the results could also guide future sampling efforts.

5.2.3 Estuary characteristics as predictors of invertebrate communities

Based on the range of data available for South African estuaries, a set of variables was selected which were deemed to be potential predictors of invertebrate communities. These were identified based on the understanding gained from earlier studies (Table 5.1).

Table 5.1. *Estuary characteristics considered in this study*

Variable name	Units	Description	Source
Mouthclass	N/a	Categorisation of mouth type	JKT data
Size	Ha	Estuary size	JKT data
Biog	N/a	Biogeograhical zone	Harrison *et al.* 2000
Geoclass	N/a	Geomorphological class	Harrison *et al.* 2000
Lat	Decimal degrees	Latitude	NRIO (1986, 1987a,b,c, 1988)
Long	Decimal degrees	Longitude	NRIO (1986, 1987a,b,c, 1988)
CPT_dist	Km	Distance from Cape Point	NRIO (1986, 1987a,b,c, 1988)
Catch_A	Km^2	Catchment area	NRIO (1986, 1987a,b,c, 1988)
Riv_lngth	Km	River length	NRIO (1986, 1987a,b,c, 1988)
Source_elev	M	Elevation of source	NRIO (1986, 1987a,b,c, 1988)
Riv_grad	1:x	River gradient	Calculated
MAR	Mm	Mean Annual Runoff	NRIO (1986, 1987a,b,c, 1988)
MAR var	%	Annual variation in MAR	NRIO (1986, 1987a,b,c, 1988)
Sed	Tonnes/ km^2/ yr	Sediment yield	NRIO (1986, 1987a,b,c, 1988)
Inter_Sltmrsh	Ha	Intertidal Saltmarsh area	"Botanical database Jul 00"
Supra_Sltmrsh	Ha	Supratidal saltmarsh area	"Botanical database Jul 00"
Sub_macrophyt	Ha	Submerged macrophyte area	"Botanical database Jul 00"
Reeds	Ha	Reed and sedge area	"Botanical database Jul 00"
Mngrve	Ha	Mangrove forest area	"Botanical database Jul 00"
Intertidal	Ha	Intertidal sand/mudflats (Benthic microalgae)	"Botanical database Jul 00"
Water	Ha	Permanent water area (Phytoplankton area)	"Botanical database Jul 00"
Rock	Ha	Intertidal rock (Macroalgae area)	"Botanical database Jul 00"
Swmpforest	Ha	Swamp forest area	"Botanical database Jul 00"
Tot habitat	Ha	Sum of vegetation type areas	"Botanical database Jul 00"

The set of variables identified in Table 5.1 were investigated using Principal Component Analysis (PCA) in order to identify a core set of relatively independent variables that characterise estuaries. Only factors with eigenvalues greater than 1 were considered (StatSoft Inc. 2004). Within these factors, the loading of individual variables was investigated to determine the nature of the factor in order to identify a minimum set of explanatory variables, usually those with the highest loading and/or explanatory power.

These variables were used in a stepwise multiple regression (backward selection) to develop a suitable model which could predict species richness in the remaining estuaries. This method only retains those variables with significant β values and with minimal intercorrelations between one another (Tolerance >0.0001) (StatSoft Inc. 2004).

Data were analysed using multiple regression analyses and generalised linear modelling (which incorporates categorical variables such as estuary type). Mouth condition of an estuary is recognised as one of the most important factors determining species richness, particularly among benthic invertebrates (De Villiers *et al.* 1999). Thus analyses were performed on permanently and temporarily open estuaries in combination and separately. Due to data deficiencies, Subtropical estuaries were not included in any of the above analyses.

5.2.4 Predicting species richness as a proportion of the available species pool

Finally, an alternative approach was tested to deal with the analytical complexities that arise because of the 'subtropical subtraction effect' (decrease in overall species from tropical to cold temperate waters). The 'species pool' for any particular estuary was defined in terms of the distributional ranges of estuarine invertebrates. Similar analyses to the above were performed in order to predict the ratio of actual species richness to the species pool.

The species ranges used in the analysis were originally devised by Bruce Emmanuel and George Branch on the basis of sampling data and a knowledge of individual systems that allowed reasonable accuracy to a resolution of 100-km zones around the coast (Emmanuel *et al.* 1987; Prof. G.M. Branch, University of Cape Town, pers. comm.), and later refined in Awad *et al.* (2000). These data were the basis of the inferred presence-absence used in earlier importance rating indices.

5.3 Results & Discussion

5.3.1 Data characteristics

At least some information on the invertebrate species present was available for 168 estuaries (66% of South African estuaries), with the majority (104 of 168 = 62%) occurring in the Warm Temperate biogeographic region (Figure 5.1). Estuaries included in this study are listed in Table 5.2 to Table 5.4

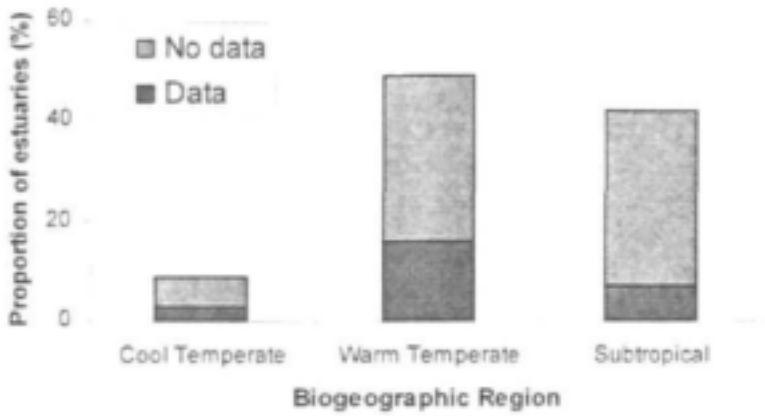


Figure 5.1. Proportion of estuaries falling into the three biogeographic regions and the proportion with available species richness data.

At least 16 estuaries (8 permanently open and 8 temporarily open) are considered to have been comprehensively sampled, using comparable methods, for both plankton and benthic fauna, including intertidal benthic fauna in open estuaries. In addition, three temporarily open estuaries have been sampled in the intertidal during open phases. Nevertheless, benthic subtidal sampling would ordinarily cover all the benthic fauna in temporarily open estuaries. If intertidal data are a reasonable indication of all benthic fauna, then one temporarily open estuary, and several more permanently open estuaries can be considered to be well sampled. Several more estuaries are well sampled for benthic fauna alone, but have not been subject to plankton studies.

The above mentioned estuaries fall predominantly within the Warm Temperate region. While data are available for most estuaries in the Subtropical region, these are mostly only available for particular taxa (e.g. Macruran and Brachyuran crustaceans in KZN estuaries: Begg 1984), which makes comparisons difficult. Further problems in using data from various studies in compiling the larger data set for all 168 estuaries, were the variability of sampling effort and methods, season and estuary status at time of sampling and the age of the sample.

Table 5.2. Available species richness data for Cold Temperate estuaries.

Name	Type	Sources	Total SR	Plankton SR	Subtidal SR	Intertidal SR
Olifants	Perm	GB, Day	43			
Berg (Groot)	Perm	GB, KH	25			25
Rietvlei/Diep	Perm	GD	35			

GB: "Green Book" Estuaries of the Cape Series; Day: Day 1981; GD: Grindley & Dudley 1988; KH: Kaljeta & Hockey 1991.

Table 5.3. Available species richness data for Cold Temperate and Warm Temperate estuaries. Estuaries in bold are considered to be comprehensivly sampled.

Name	Type	Sources	Total SR	Plankton SR	Subtidal SR	Intertidal SR
Wildevoëlvlei	Temp	GB	6			
Sand	Temp	GB, MG	22			
Lourens	Temp	CG	6			
Rooiels	Temp	KN, GB	17			6
Palmiet	Perm	KN, GB	34		1	11
Bot/Kleinmond	Temp	GB, DK, CO	62	39	20	
Onrus	Temp	GB	9			
Klein	Temp	GB	128			1
Heuningnes	Perm	KN, GB	44			32
Breë	Perm	GB, C, PT	148			26
Duiwenhoks	Perm	GB	20			
Goukou (Kaffirkuils)	Perm	GB	21			
Klein Brak	Temp	KN	25			25
Groot Brak	Temp	GB, MP, Day	90			6
Kaaimans	Perm	KN	9			9
Swartvlei	Lake	WH	49		38	32
Knysna	Bay	GB, VE, Day	310	51		
Keurbooms	Perm	GB	42			
Sout (Oos)	Perm	GB	6			
Groot (Wes)	Temp	GB	10			
Kromme	Perm	TK, WC, GB, SH	138	38	91	38
Kabeljous	Temp	KN, TK, CD	52	16	28	17
Gamtoos	Perm	KN, CA, GB, WW	78	29	43	30
Van Stadens	Temp	TK, CD	35	12	25	
Swartkops	Perm	KN, TK, GB, SH, HA	202	32	67	53
Sundays	Perm	KN, TK, CA, SH	102	6	24	59
Bushmans	Perm	KN, H	80			32
Kariega	Perm	KN, TK, CD, HO	115	37	55	51
Kowie	Perm	GB	39	24	16	
Kleinemond Oos	Temp	TK, CD	51	23	32	1
Great Fish	Perm	KN, TK, CD	49	21	23	12
Old woman's	Temp	TK, CD	33	14	23	
Mpekweni	Temp	TK, CD	49	22	30	1
Mtati	Temp	TK, CD	40	18	25	
Mgwalana	Temp	KN, CD	47	22		27
Gqutywa	Temp	TK, CD	50	21	31	
Keiskamma	Perm	KN, TK, CD	69	28	23	28
Kiwane	Temp	SO	14		14	
Tyolomnqa	Temp	KN	22			22
Lilyvale	Temp	SO	6		6	
Gxulu	Temp	SO	15		15	
Goda	Temp	SO	18		18	
Hlozi	Temp	SO	10		10	
Hickman's	Temp	SO	6		6	
Nahoon	Perm	GB, BU	109	6	80	32
Kwelera	Perm	CD	6	6		
Cintsa	Temp	SO	15		15	
Cefane	Temp	SO	15		15	
Nyara	Temp	SO	12		12	
Nxaxo/Ngqusi	Perm	DE	8	8		

Data sources: BU: Bursey 2001; C: Carter 1983; CA: Callahan 2001; CG: Cliff & Grindley 1982; CO: Connell 1974; GB: "Green Book" Estuaries of the Cape Series; CO: Coetzee 1987; Day: Day 1981; DE: Deysel 2001; DK: De Decker 1987; GD: Grindley & Dudley 1988; H: Hodgson unpubl.; HA: Hanekom *et al.* 1988; KN: this study; MG: Morant & Grindley 1982; MP: Monitoring program 1989-2001 (unpubl); PT: Pemberton 2001; SH: Scharler *et al.* 1998; SO: Sogayia 2001; TK: Teske & Woolnfge 2000; VE: Veldhuis 1987; WH: Whitfield 1989; WW: Whitfield & Wood 2003.

Table 5.4. Available species richness data for Subtropical estuaries.

Name	Type	Sources	Total species recorded	Plankton SR	Prawns & crabs SR	Benthic SR
Mbashe	Perm	BG	70			
Mngazana	Perm	Wo, BG	208	30		
Mbotyi	Temp	W	22	22		
Msikaba	Perm	W	28	28		
Mtentu	Perm	CO	10			
Little Manzimtoti	Temp	AD	3			
Durban Bay	Bay	KP	148			
Mgeni	Temp	Begg	24		24	
Mhlanga	Temp	Begg	16		16	
Mdloti	Temp	Begg	12		12	
Tongati	Temp	Begg	8		8	
Mhlali	Temp	Begg	16		16	
Seteni	Temp	Begg	5		5	
Mvoti	River mouth	Begg	6		6	
Mdlotane	Temp	Begg	3		3	
Nonoti	Temp	Begg	5		5	
Zinkwasi	Temp	Begg	23		23	
Mlalazi	Perm	Day	84			
Mhlathuze	Bay	MC, JE	172			
St Lucia	Lake	Day	84			

AD: Amazon Database; Begg: Begg 1978 – Prawns and crabs only; BG: Branch & Grindley 1979; MC: CO: Connell 1974 – mainly zooplankton; Day: Day 1981; JE: Jerling 1998/9; KP: Kim Prochaska database; Mackay & Cyrus 1998/9; W: Wooldridge 1974; Wo: Wooldridge 1977.

Complete data on the estuary characteristics selected for this study were available for a maximum of 126 estuaries (49%; Figure 5.2). As with species richness data, the largest proportion of estuaries with available data fell under the Warm Temperate region.

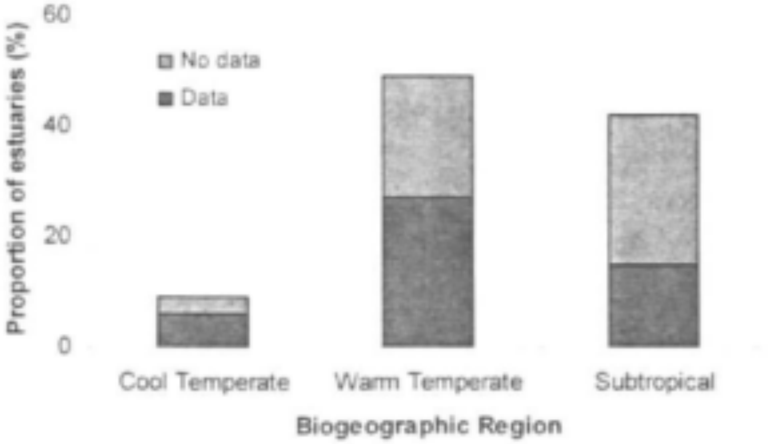


Figure 5.2. Proportion of estuaries falling into the three biogeographic regions and the proportion with available data on estuary characteristics.

5.3.2 Diversity and habitat specificity

Some 538 invertebrate taxa have been recorded in South African estuaries, although not all of these have been identified to species level, which means that some of this is likely to be duplication. More taxa have been recorded in subtidal benthic habitats than in the plankton or intertidal benthos. The groupings of taxa and their known occurrence in three main habitats is summarised in Table 5.5. Details of all taxa recorded are given in Table 5.6.

Table 5.5. Total number of species recorded in each habitat for each taxon. The numbers are not additive as many species are shared across habitats

Higher Taxon	Planktonic	Subtidal	Intertidal
Acarina	1		
Actiniaria		2	
Amphipoda	27	36	21
Anomura	5	3	5
Arachnida	1		
Asteroidea		1	
Bivalvia		24	19
Brachyura	5	15	16
Branchiura	1		
Cephalopoda			1
Chaetognatha	1		
Cladocera	1		
Cirripedia	1		
Cnidaria	1	1	
Coelenterata	1		
Copepoda	49		1
Cumacea	2	2	1
Decapoda	1		
Echinoidea		1	
Echiurida		1	2
Gastropoda		13	9
Hirudinea	1	4	
Insecta	5	2	15
Isopoda	15	21	13
Macrura	2	8	6
Mollusca	4	1	5
Mysidacea	9	6	3
Nematoda	1	1	
Nemertea		2	3
Oligochaeta		3	1
Opisthobranchia		2	1
Ostracoda	1		
Platyhelminthes	1		
Polychaeta	3	66	40
Prosobranchia		4	6
Pulmonata		1	
Tanaidacea	2	3	1
Grand TOTAL	**143**	**224**	**171**

Table 5.6. Invertebrate species recorded in Planktonic (P), Subtidal benthos (S) and Intertidal benthos (I) sampling in temperate South African estuaries

Higher Taxon	Nearest avail taxon	P	S	I
?	Ctenophora (Planktonic)	1		
	Nauplii (Planktonic)	1		
	Paranthura sp (Subtidal)		1	
Acarina	*Acarina* sp (Planktonic)	1		
Actiniaria	?*Percuiodes longimanus*		1	
	Actiniaria sp. (Subtidal)		1	
Amphipoda	*Afrochiltonia capensis*	1	1	1
	Afrochiltonia subtenuis	1		
	Amaryllis macrophthalma		1	
	Amphipod spp x 3 (Subtidal)		1	
	Amphipoda sp. (Intertidal)			1
	Amphipoda sp. (Planktonic)	1		
	Atylus guttatus	1	1	
	Atylus sp. (Planktonic)	1		
	Atylus sp. (Subtidal)		1	
	Atylus swammerdamei		1	
	Austrochiltonia capensis	1		
	Austrochiltonia subtenuis		1	1
	Caprella natalensis	1		
	Corophium acherusicum	1	1	
	Corophium sp (Intertidal)			1
	Corophium sp. (Subtidal)		1	
	Corophium triaenonyx	1	1	1
	Cymadusa filosa	1		
	Cyproidea ornata			1
	Grandidierella bonnieri	1		
	Grandidierella chelata	1	1	1
	Grandidierella lignorum	1	1	1
	Grandidierella lutosa	1	1	1
	Grandidierella sp. (Intertidal)			1
	Grandidierella sp. (Planktonic)	1		
	Grandidierella sp. (Subtidal)		1	
	Hyale maroubrae	1		
	Ichnopus sp. (Subtidal)		1	
	Lysianassa ceratina		1	1
	Lysianassa sp (Subtidal)		1	
	Lysianassa sp. (Planktonic)	1		
	Lysianassa variegata		1	
	Melita zeylanica	1	1	1
	Monoculodopsis longimana		1	
	Orchestia ancheidos		1	1
	Orchestia rectipalma			1
	Orchestia sp (Intertidal)			1
	Orchomene plicata		1	
	Paramoera capensis	1		1
	Parandania boecki		1	
	Paraphoxus boecki	1		
	Paraphoxus oculatus		1	
	Perioculodes longimanus	1	1	
	Platyischnopus herdmani	1	1	
	Podoceridae africanus		1	
	Podoceridae sp. (Subtidal)		1	
	Stenothoe galensis	1		
	Stenothoe valida	1	1	
	Urothoe coxalis		1	
	Urothoe elegans	1	1	1
	Urothoe grimaldii			1
	Urothoe pinnata	1	1	1
	Urothoe pulchella		1	1
	Urothoe serrulidactylus		1	1
	Urothoe sp. (Planktonic)	1		
Anomura	*Callianassa kraussi*		1	1
	Callianassa kraussi larvae	1		
	Callianassa kraussi post larvae	1		
	Diogenes brevirostris		1	1
	Hermit crabs (Intertidal)			1
	Unknown Prawns (Intertidal)			1
	Upogebia africana		1	1
	Upogebia africana larvae, megalope & zoea larvae	1		
	Upogebia africana postlarvae	1		
	Upogebia africana Stage 1	1		
Arachnida	*Hydracarina* sp (Planktonic)	1		
Asteroidea	*Patriella exigua*		1	
Bivalvia	*Anodonta edentula*			1
	Arcuatula capensis		1	1
	Bivalve 1 (Subtidal)		1	
	Branchidontes semistriatus		1	
	Branchidontes virgiliae		1	
	Donax serra		1	1
	Donax simplex		1	
	Donax sordidus		1	1
	Dosinia hepatica		1	1
	Eumarcia paupercula		1	1
	Lamya capensis		1	
	Loripes clausus		1	1
	Loripes sp. (Intertidal)			1
	Lucina edentula		1	1
	Lutraria lutraria		1	
	Macoma litoralis		1	1
	Macoma ordinaria			1
	Musculus virgiliae		1	
	Psammotellina capensis		1	1
	Sanguinolaria capensis		1	1
	Solen capensis		1	1
	Solen corneus		1	1
	Solen cylindraceus		1	1
	Solen sp. (Intertidal)			1
	Tellina gilchristi		1	1
	Tellina sp (Subtidal)		1	
	Tellina trilaterata		1	
	Thecalia concamerata		1	
	Unidentified bivalves (Intertidal)			1

Higher Taxon	Nearest avail taxon	P	S	I
Brachyura	Calappa hepatica		1	
	Cleistosoma edwardsi			1
	Cleistostoma algoense		1	1
	Cleistostoma edwardsii		1	1
	Cyclograpsus punctatus		1	
	Dotilla fenestrata			1
	Hymenosoma orbiculare		1	1
	Hymenosoma orbiculare larvae (Planktonic)	1		
	Leucisca squalina		1	
	Lupa pelagica		1	
	Megalopa (Planktonic)	1		
	Ocypode sp (Subtidal)		1	
	Paratylodiplax algoense		1	1
	Paratylodiplax edwardsii		1	1
	Paratylodiplax edwardsii larvae	1		
	Paratylodiplax sp. (Intertidal)			1
	Rhynchoplax bovis		1	1
	Scylla serrata		1	
	Sesarma catenata		1	1
	Sesarma catenata larvae	1		
	Sesarma eulimene		1	1
	Sesarma meinerti			1
	Thaumastoplax spiralis		1	1
	Uca annulipes			1
	Uca urvillei			1
	Megalopa (Intertidal)			1
	Zoea larvae (Planktonic)	1		
Branchiura	Argulus sp (Planktonic)	1		
Cephalopoda	Octopus granulatus			1
Chaetognatha	Sagitta sp. (Planktonic)	1		
Cirripedia	Cirripede nauplii	1		
Cladocera	Cladoceran sp (Planktonic)	1		
Cnidaria	Hydractinia kaffraria		1	
	Hydroid medusae (Planktonic)	1		
Coelenterata	"Polyps" (Planktonic)	1		
Copepoda	"Other cyclopoids" (Planktonic)	1		
	Acartia africana	1		
	Acartia longipatella	1		
	Acartia natalensis	1		
	Acartia sp (Planktonic)	1		
	Calanoides carinatus	1		
	Calanus helgolandicus	1		
	Calanus sp. (Planktonic)	1		
	Canthocalanus pauper	1		
	Centropages brachiatus	1		
	Centropages chierchiae	1		
	Centropages furcatus	1		
	Copepod sp. (Intertidal)			1
	Copepoda sp. (Planktonic)	1		
	Corycaeus africanus	1		
	Corycaeus sp. (Planktonic)	1		
	Corycaeus speciosus	1		
	Cyclops sp (Planktonic)	1		
	Ergasilid sp (Planktonic)	1		
	Eucalanus attenuatus	1		
	Euterpina acutifrons	1		
	Euterpina sp. (Planktonic)	1		
	Halicyclops sp. (Planktonic)	1		
	Harpacticoid sp. (Planktonic)	1		
	Harpacticus sp. (Planktonic)	1		
	Labidocera sp. (Planktonic)	1		
	Macrosetella gracilis	1		
	Metis sp. (Planktonic)	1		
	Microsetella norvegica	1		
	Nannocalanus minor	1		
	Oithona brevicornis	1		
	Oithona similis	1		
	Oithona sp. (Planktonic)	1		
	Oithona subtilis	1		
	Oncaea media	1		
	Oncaea mediterranea	1		
	Oncaea sp. (Planktonic)	1		
	Oncaea venusta	1		
	Paracalanus aculeatus	1		
	Paracalanus crassirostris	1		
	Paracalanus parvus	1		
	Paracalanus sp. (Planktonic)	1		
	Pontella sp (Planktonic)	1		
	Pseudodiaptomus hessei	1		
	Pseudodiaptomus nudus	1		
	Pseudodiaptomus sp (Planktonic)	1		
	Sapphirella sp. (Planktonic)	1		
	Tegastes sp (Planktonic)	1		
	Temora stylifera	1		
	Tortanus capensis	1		
Cumacea	Cumacea sp. (Subtidal)		1	
	Iphinoe truncata	1	1	1
	Cumacean (Planktonic)	1		
Decapoda	Decapod larvae (Planktonic)	1		
Echinoidea	Echinocardium cordatum		1	
Echiurida	Ochaetostoma capensis		1	1
	Unidentified Oligochaeta			1
Gastropoda	?Assimenia sp 1 (Subtidal)		1	
	?Assimenia sp 2 (Subtidal)		1	
	Alaba pinnae		1	1
	Assimenia bifasciata		1	1
	Assimenia globulus			1
	Assimenia ovata			1
	Assimenia ponsonbyi		1	
	Assimenia sp. (Intertidal)			1
	Assimenia sp (Subtidal)		1	
	Bedeba parvae		1	
	Bullia diluta		1	
	Bullia laevissima		1	
	Bullia rhodostoma			1
	Cerithidea decollata		1	
	Haminoea alfredensis		1	1

Higher Taxon	Nearest avail taxon	P	S	I
	Hydrobia dubia		1	
	Hydrobia sp. (Intertidal)			1
	Hydrobia sp. (Subtidal)		1	
	Nucella sp. (Intertidal)			1
Hirudinea	Hirudinea (Subtidal)		1	
	Hirudinean sp (Planktonic)	1		
	Leech spp x 3 (Subtidal)		1	
Insecta	Canacidae (Intertidal)			1
	Chironomid larvae		1	
	Chironomid larvae (Intertidal)			1
	Chironomid larvae (Planktonic)	1		
	Dolichopodidae (Intertidal)			1
	Dyschinus sp. (Intertidal)			1
	Ephemeroptera nymphs (Planktonic)	1		
	Ephydridae (Intertidal)			1
	Ephydridae (Subtidal)		1	
	Insect larvae (Planktonic)	1		
	Insect pupae (Intertidal)			1
	Odonata numphs (Planktonic)	1		
	Oxytelus sp. (Intertidal)			1
	Sphaeroceridae (Intertidal)			1
	Stratomyidae (Intertidal)			1
	Tabanid larvae (Intertidal)			1
	Unidentified Insecta (Intertidal)			1
	Unid. Insecta 1 (Intertidal)			1
	Unid. Insecta 2 (Intertidal)			1
	Unid. Insecta 3 (Intertidal)			1
	Unidentified larvae (Planktonic)	1		
	Xanthocanace (Intertidal)			1
Isopoda	*Anopsilana ?fluviatilis*		1	
	Anthurid sp. (Planktonic)	1		
	Cirolana cranchii		1	
	Cirolana fluviatilis	1	1	1
	Cirolana hirtipes	1	1	1
	Cirolana sp (Planktonic)	1		
	Coralana africana		1	
	Corallana africana	1		
	Cyathura carinata		1	1
	Cyathura estuaria	1	1	1
	Cymodoce velutina	1	1	
	Cymodocella algoense		1	
	Cymodocella pustulata		1	
	Eurydice longicornis	1	1	1
	Eurydice sp immature	1		
	Excirolana natalensis	1	1	
	Exosphaeroma hylecoetes	1		
	Exosphaeroma hylocoetes		1	1
	Exosphaeroma porrectum		1	
	Exosphaeroma sp immature	1		
	Exosphaeroma truncatitelson		1	
	Exosphaeroma variegata			1
	Leptanthura laevigata	1		
	Leptanthura sp (Intertidal)			1
	Ligia sp. (Intertidal)			1

Higher Taxon	Nearest avail taxon	P	S	I
	Ligia sp. (Subtidal)		1	
	Nerocila sp. (Intertidal)			1
	Parasitic isopod (Planktonic)	1		
	Paridotea ungulata		1	1
	Pontogeloides latipes		1	1
	Sphaeroma sp. (Subtidal)		1	
	Sphaeromid sp. (Planktonic)	1		
	Synidotea sp (Subtidal)		1	
	Unidentified Isopoda (Intertidal)			1
	Xenathura sp. (Subtidal)		1	
Macrura	*Alpheus crassimanus*		1	1
	Alpheus frontalis			1
	Betaeus jucundus		1	1
	Macropetasma africanum		1	
	Palaemon pacificus	1	1	1
	Palaemon peringueyi	1	1	
	Penaeus canaliculatus			1
	Penaeus indicus		1	
	Penaeus japonicus			1
	Penaeus latisulcatus		1	
	Penaeus monodon		1	
Mollusca	Bivalve sp. (Intertidal)			1
	Brachiodontes virgiliae			1
	Gastropd larvae (Planktonic)	1		
	Gastropd veligers (Planktonic)	1		
	Lamellibranch juv (Planktonic)	1		
	Lamellibranch veligers (Planktonic)	1		
	Unid. Mollusc spp x 3 (Intertidal)			1
	Finella natalensis		1	
Mysidacea	*Acanthomysis indica*	1	1	
	Gastrosaccus brevifissura	1	1	1
	Gastrosaccus psammodytes	1	1	1
	Mesopodopsis similis	1		
	Mesopodopsis slabberi	1		1
	Mesopodopsis wooldridgei	1	1	
	Mysidopsis major	1	1	
	Mysidopsis similis	1		
	Rhopalophthalmus terranatalis	1	1	
Nematoda	Nematode sp (Planktonic)	1		
	Nematode sp (Subtidal)		1	
Nemertea	*Gorgonorhynchus* sp. (Intertidal)			1
	Nemertea (Subtidal)		1	
	Polybrachiorhynchus dayi		1	1
	Unid. Nemertea (Intertidal)			1
Oligochaeta	Oligochaete spp x 3 (Subtidal)		1	
Opisthobranchia	*Hydatina physis*		1	1
	Notarchus leachi		1	
Ostracoda	Ostracod sp (Planktonic)	1		
Platyhelminthes	Turbellaria (Planktonic)	1		
Polychaeta	*Amphithoe falsa*		1	
	Arenicola loveni		1	1
	Armandia leptocirrus		1	1
	Boccardia sp (Intertidal)			1

Higher Taxon	Nearest avail taxon	P	S	I
	Capitella capitata		1	1
	Capitellidae sp. (Intertidal)			1
	Ceratonereis erythraensis		1	1
	Ceratonereis keiskamma		1	1
	Ceratonereis spp. (Intertidal)			1
	Cirratulid sp. (Intertidal)			1
	Cirratulidae sp. (Subtidal)		1	
	Cossura coasta			1
	Cossura sp. (Subtidal)		1	
	Dendronereis arborifera		1	1
	Desdemona ornata		1	1
	Diopatra neapolitana		1	1
	Eteone siphodonta		1	
	Eunice antennata		1	
	Eurythoe complanata		1	
	Exogene normalis		1	
	Ficopomatus enigmatica		1	
	Glycera convoluta		1	
	Glycera sp. (Intertidal)			1
	Glycera tridactyla		1	1
	Glycinde capensis			1
	Goniadella gracilis		1	
	Goniadopsis incerta		1	
	Goniadopsis maskallensis		1	
	Harmothoe aequiseta		1	
	Janua brasiliensis		1	
	Leodamas johnstonei		1	
	Levinsenia oculata		1	
	Lumbrineris breviorra			1
	Lumbrinereis sp. (Intertidal)			1
	Lumbrinereis tetraura			1
	Lumbrineris coccinea		1	
	Lumbrineris sp. (Subtidal)		1	
	Lumbrineris tetraura		1	
	Magelona cincta		1	1
	Maldanidae sp. (Subtidal)		1	
	Marphysa sanguinea		1	1
	Melanita zeylanica		1	
	Mercierella enigmatica		1	
	Micronephthys sphaerocirrata		1	
	Mysta siphodonta		1	
	Nephtys capensis		1	1
	Nephtys hombergi		1	1
	Nephtys sp. (Intertidal)			1
	Nephtys sp. (Subtidal)		1	
	Nephtys tulearensis		1	
	Nereid sp. (Intertidal)			1
	Nereis pelagica		1	
	Nereis sp. (Subtidal)		1	
	Nereis willeyi		1	
	Notomastus fauveli		1	
	Notomastus sp. (Intertidal)			1
	Paralocydonia sp. (Intertidal)			1
	Paralycodonia sp. (Intertidal)			1
	Pectinaria capensis			1
	Perinereis nuntia			1
	Phyllodoce sp. (Subtidal)		1	
	Phylo sp. (Subtidal)		1	
	Poecilochaetus serpens		1	
	Polychaete 1 (Subtidal)		1	
	Polychaete 2 (Subtidal)		1	
	Polychaete 3 (Subtidal)		1	
	Polychaete 4 (Subtidal)		1	
	Polychaete larvae (Planktonic)	1		
	Polychaete sp (Planktonic)	1		
	Polychaete unknown (Subtidal)		1	
	Potamilla reniformis		1	
	Prionospio pernana		1	
	Prionospio pinnata			1
	Prionospio saldanha		1	
	Prionospio sexoculata	1	1	1
	Prionospio sp. (Subtidal)		1	
	Pseudonereis variegata		1	
	Pseudopolydora sp. (Subtidal)		1	
	Sabellastarte longa		1	
	Schistomeringos neglecta			1
	Scolelepis squamata			1
	Scoleiepsis squamata		1	1
	Sigalion capense		1	
	Spionidae sp. (Intertidal)			1
	Spionidae sp. (Subtidal)		1	
	Syllidae sp. (Subtidal)		1	
	Syllis variegata		1	
	Thelepus comatus		1	
	Trypanosyllis gemmulifera		1	
	Unid. Polychaete (Intertidal)			1
	Unid. Polychaete 1 (Intertidal)			1
	Unid. Polychaete 2 (Intertidal)			1
	Unid. Polychaete 3 (Intertidal)			1
Prosobranchia	Littorina scabra		1	
	Nassarius kraussianus		1	1
	Nassarius sp. (Intertidal)			1
	Natica gaualteriana		1	
	Natica genuana			1
	Natica gualteriana			1
	Natica sp. (Intertidal)			1
	Natica tecta		1	1
Pulmonata	Siphonaria sp. (Subtidal)		1	
Tanaidacea	Apseudes digitalis	1	1	1
	Tanaid sp. (Planktonic)	1		
	Tanaid sp. (Subtidal)		1	
	Tanais philetaerus		1	
Unknown	Gebia africana			1

Only 3% of taxa have been identified in all three invertebrate communities (Figure 5.3). At least 12 species have been found to be shared between the plankton and subtidal benthos, many of these, along with the species found in all three habitats, are larvae of the benthic species. Only 26% of benthic species are shared between the intertidal and subtidal habitats. The degree of habitat specificity indicated by Figure 5.3 may be exaggerated, however, since roughly half of the taxa recorded in separate habitats have not been identified to species level in the various studies. Nevertheless, it can still be concluded that habitat specificity appears to be fairly high.

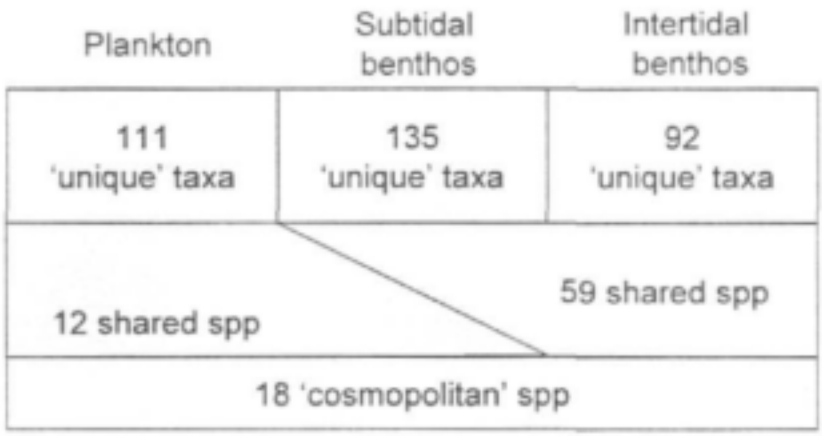


Figure 5.3. Recorded distribution of 538 invertebrate taxa among different estuarine habitats in temperate South African estuaries. Note, however, that 55%, 39% and 61% of the 'unique' taxa in plankton, subtidal and intertidal benthos, respectively, were not identified to species level , and thus that 'uniqueness' is probably overestimated. 2 species were shared between intertidal and plankton habitats.

5.3.3 Relationships between invertebrate sub-communities

For the 16 comprehensively-sampled estuaries, there was a significant correlation between subtidal benthic species richness and overall richness. However, there was poor correlation between each of the separate components (Table 5.7). This suggests that subtidal benthic fauna could be a reasonably good indicator of richness in estuaries where only data on these species exists. Nevertheless, it may not be sufficient considering the diversity that intertidal areas add to permanently open estuaries and the fact that factors affecting plankton richness may differ considerably from those affecting benthic richness.

Table 5.7. Correlation between total species richness and species richness of different invertebrate communities within an estuary. Only comprehensively-sampled estuaries were included (n=16). Only permanently open estuaries (n = 8) are included in correlations with intertidal fauna. Significant correlations (p>0.05) are shown in bold.

Species Richness	Total	Intertidal	Subtidal	Plankton
Intertidal	.57	*	*	*
Subtidal	**.80**	.21	*	*
Plankton	.43	.01	.27	*

5.3.4 Correlation of estuary characteristics

A correlation matrix of the 23 estuary characteristics selected for this study is presented in Table 5.8.

Table 5.8. Correlation between estuary characteristics of the permanently open and temporarily open/closed estuaries used in this study

Variable name	Mouthclass	Size (ha)	Biog	Geoclass	Lat (decdeg)	Long (decdeg)	CPT_dist (km)	Catch_A (sq km)	Riv_lngth (km)	Source_elev (m)	Riv_grad (1:x)
Mouthclass	1.00	-0.34	0.00	0.43	-0.12	0.17	0.14	-0.46	**-0.63**	**-0.72**	**-0.56**
Size	-0.34	1.00	-0.24	-0.26	-0.13	-0.27	-0.19	0.24	0.36	0.38	0.31
Biog	0.00	-0.24	1.00	-0.23	-0.32	**0.83**	**0.83**	-0.07	0.05	-0.17	0.25
Geoclass	0.43	-0.26	-0.23	1.00	0.05	-0.11	-0.14	-0.30	-0.45	-0.45	**-0.52**
Lat	-0.12	-0.13	-0.32	0.05	1.00	**-0.65**	**-0.70**	-0.10	-0.02	0.24	-0.13
Long	0.17	-0.27	**0.83**	-0.11	**-0.65**	1.00	**0.99**	-0.15	-0.02	-0.36	0.21
CPT_dist	0.14	-0.19	**0.83**	-0.14	**-0.70**	**0.99**	1.00	-0.10	0.01	-0.33	0.25
Catch_A	-0.46	0.24	-0.07	-0.30	-0.10	-0.15	-0.10	1.00	**0.82**	**0.69**	**0.59**
Riv_lngth	**-0.63**	0.36	0.05	-0.45	-0.02	-0.02	0.01	**0.82**	1.00	**0.82**	**0.82**
Source_elev	**-0.72**	0.38	-0.17	-0.45	0.24	-0.36	-0.33	**0.69**	**0.82**	1.00	**0.50**
Riv_grad	**-0.56**	0.31	0.25	**-0.52**	-0.13	0.21	0.25	**0.59**	**0.82**	0.50	1.00
MAR	0.11	-0.08	**-0.55**	**0.52**	0.20	-0.44	-0.48	-0.22	-0.27	-0.03	-0.46
MAR var	0.20	-0.20	0.48	-0.16	-0.38	**0.68**	**0.67**	-0.04	0.03	-0.39	0.34
Sed	-0.42	0.04	0.30	-0.34	-0.07	0.28	0.27	0.48	**0.70**	**0.54**	**0.57**
Inter_Sltmrsh	**-0.50**	**0.58**	-0.14	-0.34	-0.16	-0.21	-0.13	0.41	0.39	0.48	0.31
Supra_Sltmrsh	-0.24	**0.98**	-0.27	-0.17	-0.19	-0.25	-0.17	0.22	0.30	0.28	0.25
Sub_macrophyt	-0.17	**0.95**	-0.27	-0.14	-0.10	-0.24	-0.18	0.05	0.17	0.18	0.16
Reeds	-0.18	**0.96**	-0.26	-0.13	-0.13	-0.23	-0.17	0.07	0.21	0.21	0.19
Mngrve	-0.17	-0.02	0.05	-0.11	-0.10	0.09	0.09	-0.03	-0.01	-0.00	0.03
Bnth_microalg	-0.38	**0.63**	-0.24	-0.26	0.19	-0.41	-0.36	0.14	0.22	0.32	0.13
Phytplnktn	-0.49	**0.82**	-0.08	-0.41	-0.10	-0.14	-0.07	0.42	0.59	**0.60**	**0.51**
Macroalg	0.18	-0.03	0.12	0.01	-0.02	0.16	0.15	-0.09	-0.10	-0.20	0.12
Tot habitat	-0.34	**0.99**	-0.25	-0.25	-0.13	-0.26	-0.18	0.25	0.36	0.37	0.30

Table 5.8. Correlation between estuary characteristics of the permanently open and temporarily open/closed estuaries used in this stud contd.

Variable name	MAR (mm)	MAR var (%)	Sed (t/sq km/yr)	Inter_ Sltmrsh (ha)	Supra_ Sltmrsh (ha)	Sub_ macrophyt (ha)	Reeds (ha)	Mngrve (ha)	Bnth_ microalg (ha)	Bnth_ microalg (ha)	Phytplnktn (ha)	Macroalg (ha)	Tot_habitat (ha)
Mouthclass	0.11	0.20	-0.42	**-0.50**	-0.24	-0.17	-0.18	-0.17	-0.38	-0.38	-0.49	0.18	-0.34
Size	-0.08	-0.20	0.04	**0.58**	**0.98**	**0.95**	**0.96**	-0.02	**0.63**	**0.63**	**0.82**	-0.03	**0.99**
Biog	**-0.55**	0.48	0.30	-0.14	-0.27	-0.27	-0.26	0.05	-0.24	-0.24	-0.08	0.12	-0.25
Geoclass	**0.52**	-0.16	-0.34	-0.34	-0.17	-0.14	-0.13	-0.11	-0.26	-0.26	-0.41	0.01	-0.25
Lat	0.20	-0.38	-0.07	-0.16	-0.19	-0.10	-0.13	-0.10	0.19	0.19	-0.10	-0.02	-0.13
Long	-0.44	**0.68**	0.28	-0.21	-0.25	-0.24	-0.23	0.09	-0.41	-0.41	-0.14	0.16	-0.26
CPT_dist	-0.48	**0.67**	0.27	-0.13	-0.17	-0.18	-0.17	0.09	-0.36	-0.36	-0.07	0.15	-0.18
Catch_A	-0.22	-0.04	0.48	0.41	0.22	0.05	0.07	-0.03	0.14	0.14	0.42	-0.09	0.25
Riv_lngth	-0.27	0.03	**0.70**	0.39	0.30	0.17	0.21	-0.01	0.22	0.22	0.59	-0.10	0.36
Source_elev	-0.03	-0.39	**0.54**	0.48	0.28	0.18	0.21	0.00	0.32	0.32	0.60	-0.20	0.37
Riv_grad	-0.46	0.34	**0.57**	0.31	0.25	0.16	0.19	0.03	0.13	0.13	0.51	0.12	0.30
MAR	1.00	**-0.55**	-0.31	-0.16	-0.04	-0.02	-0.02	-0.06	-0.08	-0.08	-0.21	-0.14	-0.09
MAR var	**-0.55**	1.00	0.25	-0.16	-0.17	-0.17	-0.16	0.00	-0.26	-0.26	-0.15	0.27	-0.19
Sed	-0.31	0.25	1.00	0.17	-0.01	-0.07	-0.02	0.14	-0.06	-0.06	0.35	0.05	0.06
Inter_Sltmrsh	-0.16	-0.16	0.17	1.00	0.49	0.38	0.41	-0.03	**0.62**	**0.62**	**0.66**	-0.11	**0.61**
Supra_Sltmrsh	-0.04	-0.17	-0.01	0.49	1.00	**0.96**	**0.97**	-0.02	**0.53**	**0.53**	**0.75**	-0.02	**0.97**
Sub_macrophyt	-0.02	-0.17	-0.07	0.38	**0.96**	1.00	**0.98**	-0.01	**0.53**	**0.53**	**0.68**	-0.03	**0.94**
Reeds	-0.02	-0.16	-0.02	0.41	**0.97**	**0.98**	1.00	-0.02	**0.52**	**0.52**	**0.73**	0.00	**0.96**
Mngrve	-0.06	0.00	0.14	-0.03	-0.02	-0.01	-0.02	1.00	-0.04	-0.04	-0.01	-0.03	-0.02
Bnth_microalg	-0.08	-0.26	-0.06	**0.62**	**0.53**	**0.53**	**0.52**	-0.04	1.00	1.00	**0.55**	-0.10	**0.65**
Phytplnktn	-0.21	-0.15	0.35	**0.66**	**0.75**	**0.68**	**0.73**	-0.01	**0.55**	**0.55**	1.00	0.14	**0.85**
Macroalg	-0.14	0.27	0.05	-0.11	-0.02	-0.03	0.00	-0.03	-0.10	-0.10	0.14	1.00	0.01
Tot habitat	-0.09	-0.19	0.06	**0.61**	**0.97**	**0.94**	**0.96**	-0.02	**0.65**	**0.65**	**0.85**	0.01	1.00

5.3.5 Principal components analysis of estuary characteristics

Six factors with eigenvalues greater than 1 were extracted, explaining over 83% of the variance in the data on permanently open and temporarily open/closed Temperate estuaries (Table 5.9). The swamp forest variable was excluded as it did not apply to any estuaries in the sample. Analysis of the scree plot indicated that the first three factors were most important in determining variation in the dataset but all 6 factors identified above were considered.

Table 5.9. Factors extracted during PCA with eigenvalues >1.

Factor	Eigenvalue	Proportion of variance explained (%)	Cumulative variance explained (%)
1	7.8	33.9	33.9
2	4.8	20.9	54.8
3	3.2	14.0	68.8
4	1.2	5.3	74.1
5	1.2	5.1	79.1
6	1.0	4.4	83.6

The pattern of variable correlations with each factor are given in Table 5.10, *but can be* summarised as follows:

1. Primarily habitat and area related variables linked to estuary characteristics which appear to be linked to overall size of the system (catchment area, river length and gradient). Total habitat area and river lengths were used;
2. Flow characteristics which appear related to biogeographic zone, rainfall, sediment yields and gradient. MAR, distance from Cape Point and river gradient were used;
3. Similar to factor 1, with catchment area and habitat areas of specific plant communities being extracted. Submerged macrophyte habitat area was used;
4. Intertidal rocky area;
5. No strongly correlated variables were identified; and
6. Mangrove habitat area.

Table 5.10. Pattern of variable correlations with factors extracted using Principal Components Analysis (PCA). Values greater than 0.5 are considered strong correlations and are marked in bold.

	Factor					
Variable name	1	2	3	4	5	6
Mouthclass	**0.60**	0.23	0.47	-0.16	-0.23	-0.08
Size	**-0.91**	0.11	0.38	0.02	-0.02	0.01
Biog	0.27	**-0.76**	0.19	0.00	0.21	-0.08
Geoclass	0.42	0.48	0.17	0.17	-0.45	0.02
Lat	0.00	0.49	**-0.52**	-0.48	0.20	0.15
Long	0.37	**-0.80**	0.39	0.16	-0.02	-0.03
CPT_dist	0.29	**-0.81**	0.43	0.18	-0.01	-0.06
Catch_A	**-0.51**	-0.34	**-0.50**	0.08	-0.32	-0.13
Riv_lngth	**-0.64**	-0.49	-0.49	0.03	-0.25	-0.01
Source_elev	**-0.68**	-0.12	**-0.64**	0.08	-0.07	0.00
Riv_grad	**-0.51**	**-0.66**	-0.23	-0.16	-0.14	0.07
MAR	0.13	**0.70**	-0.13	0.32	-0.34	0.10
MAR var	0.26	**-0.68**	0.32	-0.25	-0.05	-0.01
Sed	-0.27	**-0.64**	-0.38	0.04	-0.21	0.22
Inter_Sltmrsh	**-0.70**	-0.07	-0.04	0.09	0.22	-0.31
Supra_Sltmrsh	**-0.85**	0.14	0.45	0.06	-0.12	0.04
Sub_macrophyt	**-0.78**	0.21	**0.52**	0.01	-0.04	0.09
Reeds	**-0.80**	0.18	**0.51**	0.01	-0.09	0.10
Mangrove	0.00	-0.12	-0.02	0.42	0.38	**0.76**
Intertidal mud/sandflat	**-0.68**	0.23	0.05	-0.16	0.44	-0.19
Water area	**-0.90**	-0.17	0.10	-0.09	-0.06	0.06
Rock area	0.08	-0.17	0.23	**-0.66**	-0.25	0.40
Tot habitat	**-0.92**	0.10	0.38	0.00	-0.03	0.02

The stepwise regression analyses yielded some significant models for predicting species diversity in temperate estuaries (Table 5.11). Generalised linear modelling provided the same result, since categorical variables (e.g. estuary type) did not make a significant contribution to the models. The fact that predictive models could not be obtained in all instances, with no success in the case of intertidal species richness, is probably largely related to the sample sizes involved, especially when estuaries were separated by type. The significant regression models obtained for total species richness and subtidal benthic species richness (Table 5.12, Table 5.13), were each based on different explanatory variables.

Table 5.11. Degree of success in predicting estuarine invertebrate diversity from broadscale estuarine characteristics. Perm = permanently open, Temp = temporarily open/closed. All analyses were for temperate estuaries only.

Attribute	Perm & Temp combined	Perm only	Temp only
Total species richness	$P < 0.001$	n.s.	n.s.
Plankton species richness	n.s.	n.s.	n.s.
Subtidal benthos species richness	$P < 0.001$	$P < 0.01$	$P < 0.01$
Intertidal benthos species richness	n.s.	n.s.	n/a

River gradient was retained as the most significant uncorrelated predictor of total species richness (Table 5.12). This variable may be linked to sediment characteristics and other variables which determine species richness in estuaries, where low gradients will result in slow water flow, higher deposition rates and increased habitat stability (Knox 2003). It also appears that low gradient is associated with water clarity in the warm temperate region, a characteristic which is often associated with high species diversity in estuaries (Day 1981). Nevertheless, the regression was far too weak to be a reliable predictor of species richness.

Table 5.12. Model predicting total species richness in permanently open and temporarily open/closed Temperate estuaries (n=45). R^2=0.191, Adj. R^2= 0.172, $F_{1,43}$ = 10.137, p<.005. SE of estimate = 39.677.

Variables	Beta	SE of Beta	B	SE of B	T(43)	P
Intercept			20.42	9.70	2.10	0.04
Riv_grad (1:x)	0.44	0.14	0.22	0.07	3.18	0.003

Subtidal species richness across all estuaries in the sample was significantly correlated with the area of submerged macrophytes (typically eelgrass *Zostera capensis*), and the area of mangroves. While there are no species that are restricted to either of these habitats in South African estuaries (Day 1981, de Villiers *et al.* 1999), they support characteristic communities and usually add significantly to the diversity of species that an estuary supports. Moreover, submerged macrophytes are usually more extensive in larger estuaries, and size is likely to be positively correlated with diversity. Given the above finding that subtidal benthic diversity is significantly correlated with overall diversity, it could be possible to use the model described in Table 5.13 to provide an estimate of relative species richness in temperate estuaries. However, the regression is again a fairly weak one, albeit stronger than that for total species richness. The degree of error would be high, especially as one would have to make use of two models to get to overall species richness.

Table 5.13. Model predicting subtidal benthic species richness in permanently open and temporarily open/closed temperate estuaries (n=26). R^2=0.486, Adj. R^2= 0.440, F2, 23 = 10.855, p<.001. SE of estimate = 16.727.

Variables	Beta	SE of Beta	B	SE of B	T(23)	P
Intercept			18.85	3.93	4.79	0.00008
Submerged macrophyte area (ha)	0.51	0.15	2.08	0.61	3.41	0.002
Mangrove area (ha)	0.49	0.15	93.96	28.45	3.30	0.003

The above analysis is based on roughly equal numbers of permanently and temporarily open estuaries, thus over-representing the former. When estuary types were analysed separately, subtidal species richness was significantly correlated with mean annual runoff in both cases (Table 5.14, Table 5.15). This was an intuitively satisfactory result, since MAR is likely to be a predictor of other more directly influential variables such as sediment particle size, salinity and clarity which are not widely available for most estuaries in South Africa. Freshwater input and the associated sediment load and characteristics are known to be important factors in determining species richness (De Villiers *et al.* 1999). Again, goodness of fit was not very high.

Table 5.14. Model predicting subtidal species richness in permanently open temperate estuaries (n=10). R^2=0.604, Adj. R^2= 0.554, F1,8 = 12.201, p<.005. SE of estimate = 0.37925.

Variables	Beta	SE of Beta	B	SE of B	T(8)	P
Intercept			1.75	0.15	11.72	0.000003
MAR (mm)	-0.78	0.22	-0.00	0.00	-3.49	0.008

Table 5.15. Model predicting subtidal species richness in permanently open temperate estuaries (n=16). R^2=0.470, Adj. R^2= 0.432, F1,14 = 12.397, p<.005. SE of estimate = 6.59

Variables	Beta	SE of Beta	B	SE of B	T(14)	P
Intercept			34.72	4.74	7.32	0.000004
MAR (mm)	-0.69	0.19	-0.17	0.05	-3.52	0.003

5.3.6 Predicting species richness as a proportion of the available species pool

Distributional information was available for 263 invertebrate species that occur in estuaries, at the resolution of their presence or absence within 28 100-km zones around the country. Based on these distributions, species richness is relatively low on the west coast, is highest on the southeastern coast (Eastern Cape) and drops off slightly as one progresses further north toward the border with Mozambique (Figure 5.5).

Obviously not all of the species within a zone will occur in all estuaries within that zone. It was surmised that the proportion of the available species pool for an estuary that actually occurs in an estuary could be predicted on the basis of broadscale estuary characteristics. Thus a model was developed using these proportions for estuaries for which species richness data was available. Proportional occurrence was regressed against a number of possible explanatory variables. Since the overall number of taxa recorded in estuaries is double that of the number for which distributional data are available, these proportions could theoretically reach 2. However, this was not considered to be a significant shortcoming in the analysis.

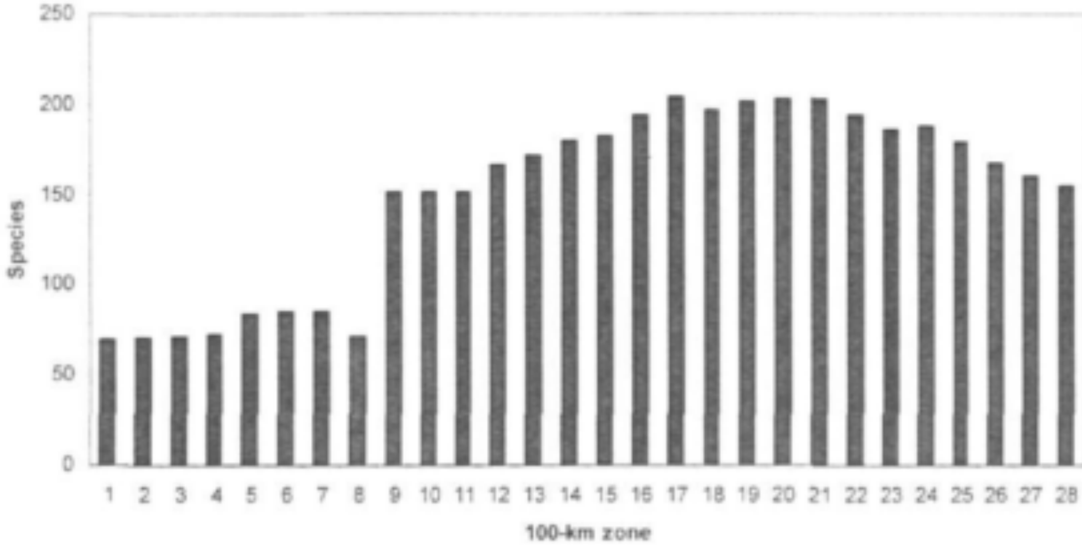


Figure 5.4. Numbers of species whose distributions coincide with each of 28 roughly 100-km zones around the coast of South Africa, from west to east, based on distributions of a total of 263 species .

For warm temperate permanently and temporarily open estuaries, species richness as a proportion of the 'species pool' was significantly positively correlated with estuary size ($n = 47$, $R^2 = 0.48$, $P < 0.0001$; Figure 5.5). The relationship was not improved when other variables such as estuary type, MAR or river gradient were taken into consideration. Variability in the data is probably partly due to differences in sampling effort.

The inclusion of Knysna estuary, an estuarine Bay, produced an intuitively good species-area relationship and increased the R^2 of the model to 0.72 (Figure 5.6).

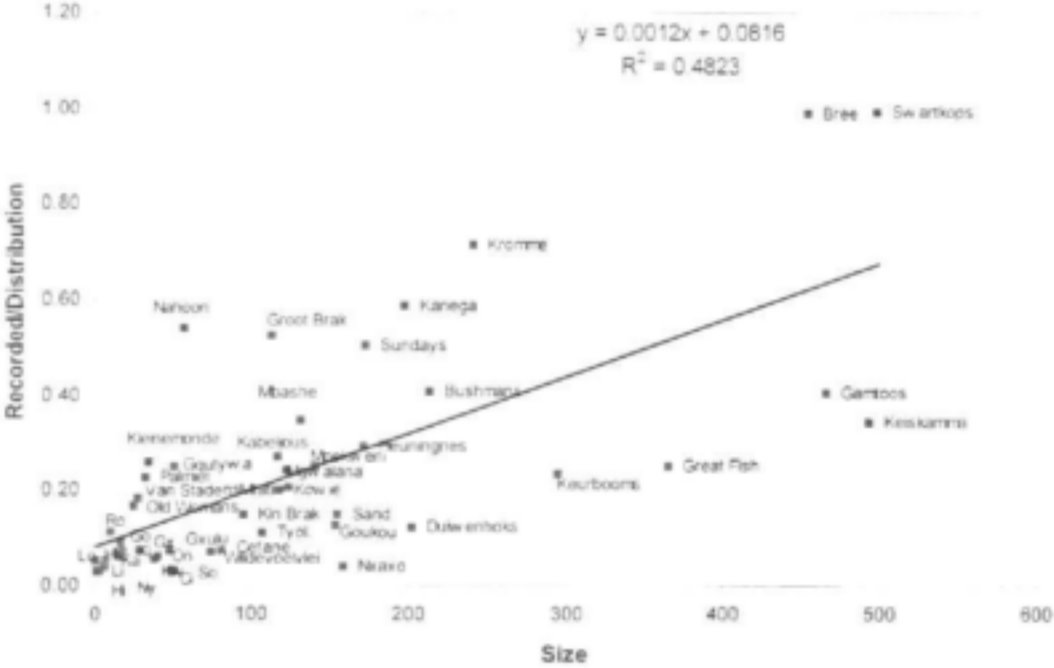


Figure 5.5. The relationship between proportion of 'possible' species (based on distribution ranges of species) that have been recorded in warm temperate estuaries, and the size of the estuary, excluding Knysna estuary, showing the positions of different estuaries in the analysis. P < 0.0001.

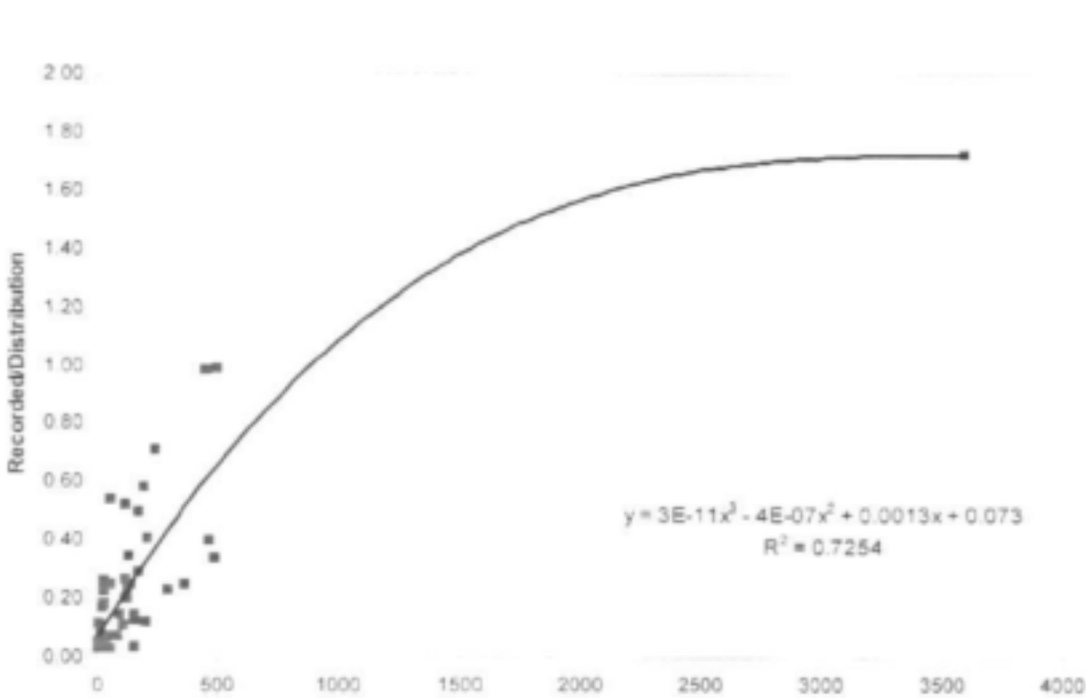
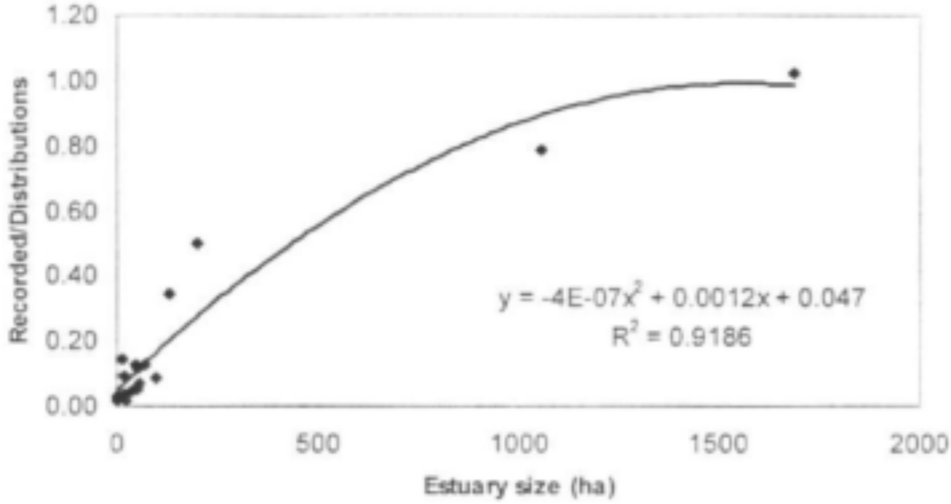


Figure 5.6. Relationship for warm temperate estuaries, as for Figure 5.5 above, but including Knysna estuary.

The analysis was repeated for subtropical estuaries, athough far fewer data were available. No significant relationship was obtained if St Lucia or Mngazana was included, but without these, the overall result is that subtropical estuaries contain a slightly lower proportion of the species pool than do their warm temperate counterparts (Figure 5.7). No comprehensive data were available for the smaller estuaries of under 100ha, which is problematic since most subtropical estuaries are in this size range. Inclusion of the under-sampled estuaries probably underestimates the proportion of the species pool contained in these estuaries, but their exclusion appears to create the opposite problem.

(a)



(b)

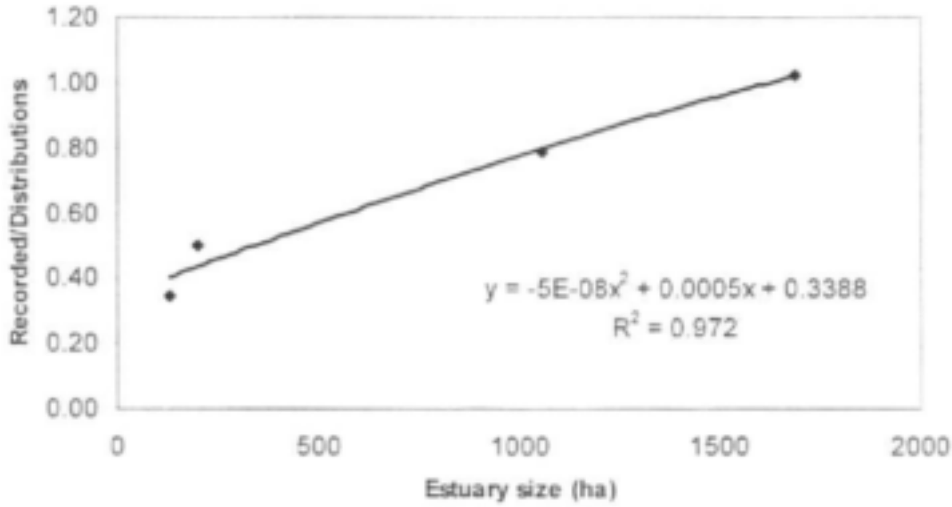


Figure 5.7. Regression between estuary size and proportion of 'possible' species (based on distribution ranges of species) that have been recorded in subtropical estuaries, excluding St Lucia (too large) and Mngazana (disproportionate sampling effort?). (a) all estuaries for which species richness data are available ($P < 0.001$) and (b) for four comprehensively sampled estuaries, $P < 0.05$.

5.4 Conclusions

Studies on estuarine invertebrates have tended to concentrate on one of the major groups, such as plankton or subtidal benthos, with a relatively small proportion of studies attempting to study the full complement of sub-communities. In particular, there is so little known about the meiofauna that this component could not be considered in this study. The relationships between the macrofaunal groups are better understood but have not been well described. No previous attempt has been made to collate the invertebrate data of all South African estuaries, and this study provides some new insight into the relative contribution that these sub-communities make to estuarine biodiversity. This study found that there is relatively little overlap between species recorded in the plankton, subtidal and intertidal macrobenthos. This suggests that data on invertebrate biodiversity for only one or two of these groups would not adequately represent the biodiversity of an estuary. This is interesting in that several previous studies of benthic invertebrates have ignored intertidal sampling based on the assumption that it would probably not add much to overall diversity (Wooldridge, pers. comm.). Indeed, data suggest that this habitat could add as much as 17% to overall diversity. Nevertheless, it was also found that diversity of the dominant group, the subtidal benthos, is correlated with overall invertebrate diversity, probably largely by virtue of its dominance. The other groups would not be adequate predictors of overall levels of invertebrate diversity.

Significant regressions were found for overall species richness and for subtidal benthos richness in temperate estuaries, but not for plankton or intertidal species richness. The regressions had rather weak correlations, however, and would not make satisfactory models for predicting species richness. Although one model for predicting subtidal benthos was slightly stronger, using this as a surrogate for species richness (see above) would simply result in compounding the error. The stepwise regression process selected river gradient, submerged macrophyte area, mangrove area and MAR as explanatory variables in these models.

From the above process it emerged that the way in which the multiple characteristics of estuaries combine to influence invertebrate community patterns could not be satisfactorily distilled from the data available. Thus a slightly different approach was taken, which was to investigate how many species of the possible number of species within whose distribution an estuary lies would be expected to occur in that estuary. This approach neutralises the added complexity that is otherwise created by the subtropical subtraction effect and the irregularities in this pattern due to geographical patterns and features. Indeed, the broadscale pattern of estuarine invertebrate species richness around the coast is not one of steadily increasing richness from west to east, but increases irregularly up to the Eastern Cape before declining again towards Kosi Bay.

The results of this study suggest that estuary size is the most important variable determining the number of potential species that actually occur in an estuary. This is completely congruent with ecological theory, except that it might be expected that in estuaries, factors such as estuary type and river gradient (which probably affects water clarity, at least in temperate estuaries) might also be important. Mouth condition plays an important role in the ecology of certain invertebrate species for which part of the life cycle is marine. These species do not survive well, if at all, in temporarily open estuaries. The fact that they include some of the most conspicuous and abundant species, such as the mudprawn *Upogebia africana*, means that mouth condition is highly significant in determining invertebrate community structure. However, the actual proportion of species that are affected is not known to be very high, and thus estuary type per se might not have a more significant influence on species diversity than estuary size. Estuary size is correlated with habitat areas and habitat diversity, which would account for much of this. It is also correlated with estuary type, in that estuaries that are permanently open tend to be larger than those that are not. The results of these regressions also had a relatively good fit, suggesting that it would be acceptable to use them to predict species richness for estuaries for which data are lacking, at least as an interim measure until more data becomes available.

The goodness of fit obtained in the final analysis was higher than expected, given the complexity of invertebrate communities, difficulties in describing the factors that shape them, and the paucity of data. Furthermore, it is important to bear in mind the purpose of using a predictive equation, which is simply to divide the countries estuaries into deciles in terms of their importance for invertebrates, so that estuaries can be rated in the top tenth, second-top tenth, etc. Given this application, the level of accuracy is probably sufficient to achieve a reliable result. This will be investigated in the final chapter.

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6. AN UPDATED IMPORTANCE RATING OF ALL SOUTH AFRICAN ESTUARIES.

Jane Turpie

6.1 Introduction

This chapter uses the results of the previous chapters to update the importance rating of South African estuaries. Changes made are described for each component of the index, and the updated overall rating system is presented.

6.2 The estuary list

The estuary list has been expanded to include Verlorenvlei, due to widespread opinion that this system should have been included in the list of functional estuaries in South Africa. While Langebaan Lagoon is effectively estuarine in nature, and should be taken into consideration in estuarine conservation planning, it is not technically an estuary, and will not be subject to resource directed measures, and is therefore not included in the study.

6.3 Measures of area

No changes have been made to the estimates of area, since no new data have come to light. However, the area of Durban Bay, which was previously omitted due to a mistaken impression of lack of data, is now included (1060 ha – Begg 1978). The present-day accuracy of this estimate still needs to be verified, as do some estimates for other estuaries.

6.4 Importance for plants

No changes have been made to the botanical elements in the importance rating. These data are considered to be adequate and reliable.

6.5 Importance for invertebrates

Invertebrate scores were updated from those based on inferred presence of species based on their coastal distribution patterns. Due to the nature of data available, the invertebrate index itself had to be revised.

The importance rating index for biotic components has up to now required data on the presence/absence or abundance of individual species in each estuary as well as in all the estuaries in the country as a whole (number of estuaries in which a species occurs, or total estuarine or coastal population). This study has confirmed the fact that it would be impossible to model the presence or absence of the hundreds of species of estuarine invertebrates in South African estuaries, species by species. It was mooted at one stage that the country's estuarine specialists might be able to devise a rule based model for each species, and thus build up the species complement for each estuary. However, further discussion and analysis of the situation and the quality of data and depth of national understanding on invertebrates and estuaries has led to the conclusion that this task could not be achieved. Thus the importance index for invertebrates would have to be based on measures such as species richness, diversity, abundance or biomass, or a combination of these. Diversity indices such as the Shannon index have been rejected in previous studies as being flawed for use in importance ratings (e.g. Turpie 1995). Thus species richness and abundance or biomass are the obvious measures for inclusion. This study has shown that reasonable estimates of species richness can be achieved for South African estuaries based on simple relationships with broadscale characterstics. Biomass data are sorely lacking, and studies on biomass seem to have decreased, with most studies now concentrating only on abundance measures. From the few data available, it appears that biomass is not a simple correlate of abundance or species richness. There are two problems that prevent the use of abundance in the index. Firstly, without a knowledge of the abundance of individual species in each estuary, one would have to create some sort of measure of overall abundance, effectively the number or density of invertebrates in an estuary. This gives equal weighting to all species, irrespective of whether they are generally common or scarce, and is complicated by the enormous size differentials within this group. Secondly, there are insufficient data on abundance in order to produce predictive relationships about abundance, and because of the size differentials, it is not expected that a simple relationship could be found.

The approach taken here is thus to determine estuarine importance for invertebrates on the basis of species richness alone. The implicit assumption in this approach are that estuaries that have high species richness will also have the highest richness of range-restricted species and of rare species. This is probably the case. What is not taken into account is the ecological importance (and economic, but this is not the concern of the importance index) associated with the abundance and productivity of invertebrates in an estuary. These elements may be weakly correlated, but are unlikely to be strongly correlated with species richness.

Where comprehensive sampling data for zooplankton, subtidal benthos, and in the case of open estuaries, intertidal benthos, exist, those species richness data were used. Data were available for all but one of the cool temperate estuaries. The Orange was estimated to contain similar species complement to the Olifants estuary, as an interim measure before data becomes available from the recent studies on that estuary. The species richness of warm temperate and subtropical estuaries for which there were insufficient or no data was estimated using the equations developed in chapter 5:

Species richness in Warm Temperate estuaries:

$$SR = 3\times10^{-11}x^3 - 4\times10^{-7}x^2 + 0.0013x + 0.073,$$

Species richness in Subtropical estuaries:

$$SR = -4\times10^{-7}x^2 + 0.0012x + 0.047$$

where x = estuary area (ha).

Estuaries were divided into deciles based on species richness and the invertebrate importance index was assigned as one of ten scores from 10 to 100, with 100 being assigned to estuaries scoring in the top 10%.

There was no correlation between the new scores and the old invertebrate scores ($n = 255$, $r^2 = 0.08$;), further supporting earlier concerns that the original index was inadequate.

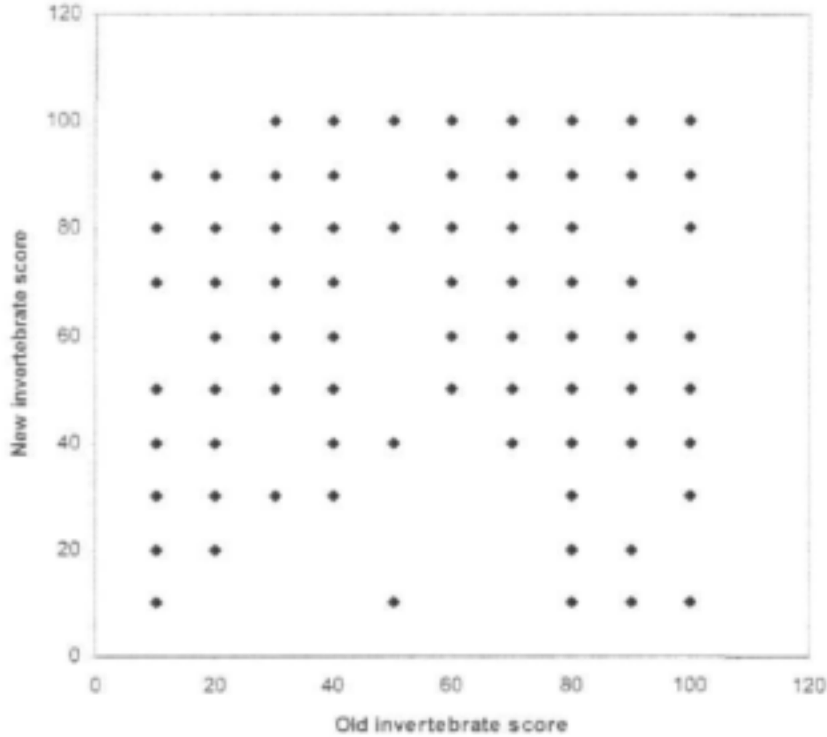

Figure 6.1. Changes in the invertebrate importance scores after the data and index were completely changed. Note that each dot may represent several estuaries.

6.6 Importance for fish

No changes were made to the fish component of the index. Despite its shortcomings (see chapter 1) it remains the most consistent, and thus comparable, data set, and is considered to be better than an index based on either (1) mixed data from Harrison and from more comprehensive studies – this would bias the index in favour of the latter, or (2) modelling fish species richness on the basis of patterns found in well-sampled estuaries (similar to the approach used for invertebrates). The latter goes against common sense in replacing empirical data with imputed data, losing information on abundance in the process. Nevertheless it was hoped to investigate the implications of such approaches, but this had to be abandoned due to limited resources and difficulties in accessing unpublished data.

6.7 Importance for birds

The existing bird data were used, with the addition of bird counts completed in the former Transkei estuaries (this study). A similar situation exists as for fish in that single counts for all estuaries could potentially be updated using regular twice-yearly counts in 23 estuaries. However, this was decided against because it would generate a bias towards the latter estuaries.

The inclusion of data for 67 new estuaries meant that the scores for many of these estuaries increased from 10 to anything from 20 (e.g. Mtakatye) to 90 (Mbotyi) (Figure 6.2). Of those that increased in score from 10, 1 went to 90, 3 to 80, 10 to 70, 7 to each of 60, 50 and 40, 5 to 30 and 11 to 20. Others for which preliminary count data had been updated with better count data increased from middle to higher scores, e.g. Nxaxo, from 50 to 90 while the score for Cebe decreased from 50 to 30. With the general increase in data in this group, overall inclusion in percentiles increased slightly, with many estuaries being 'upgraded' by one level.

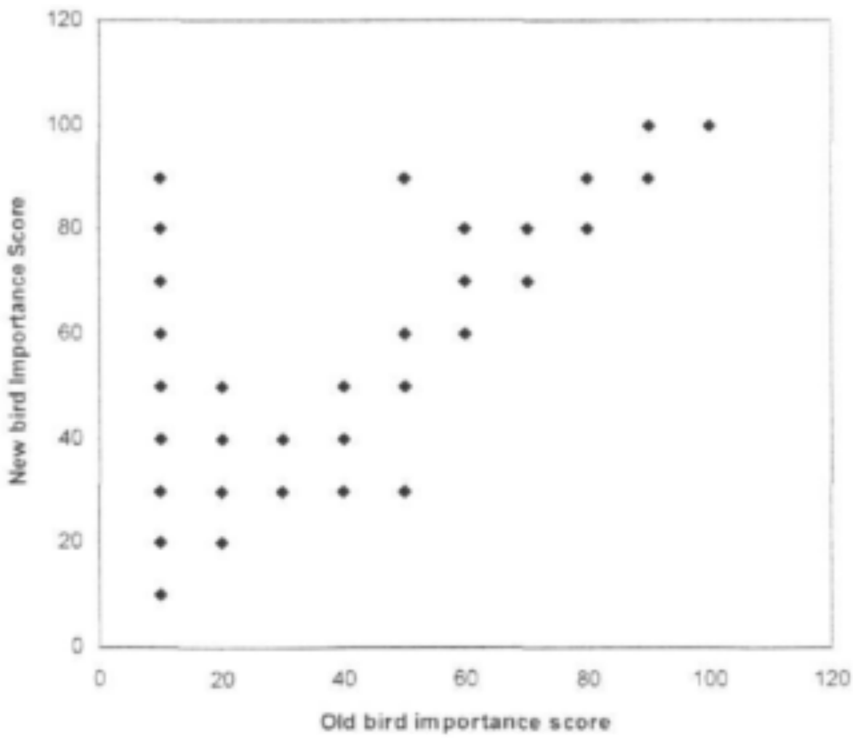

Figure 6.2. Changes in the bird importance scores after data were included for an additional 67 estuaries. Note that each dot may represent several estuaries.

6.8 Impact on the biodiversity importance scores

The invertebrate and bird indices together carry 50% of the weight in the biodiversity importance score. Thus the changes described above have a significant impact on this score, with both lower and higher ranking estuaries having increased their scores or decreased their scores.

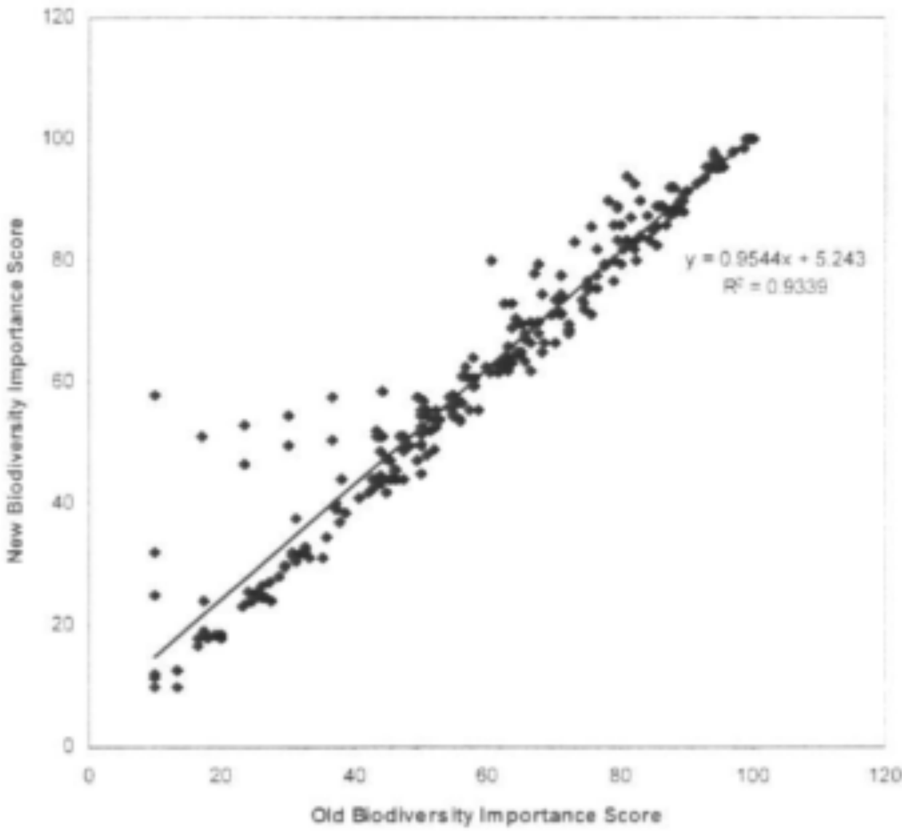

Figure 6.3. Impact of the information update on the biodiversity importance scores of South African estuaries.

6.9 Updated overall importance ratings

In spite of the radical changes in the invertebrate importance scores and the significant changes in the bird importance scores, the overall ratings of estuaries were not greatly affected (Figure 6.4). This is because the changes in the invertebrate and bird indices were buffered by other groups in the biodiversity importance rating, and the latter only carries a weight of 25% in the final importance rating. If biodiversity was to carry more weight, then these changes would have more closely resembled those in Figure 6.3. The new rankings are presented in Table 6.1 and Table 6.2.

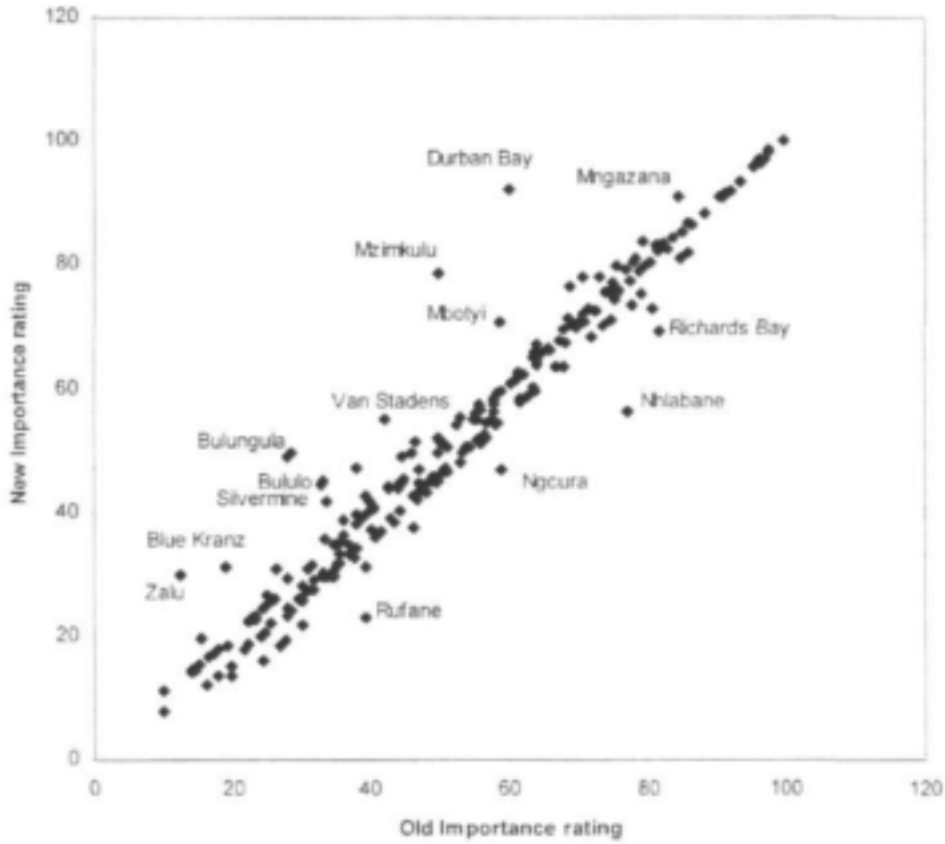

Figure 6.4. Impact of the information update on the overall importance ratings of South African estuaries. A few of the estuaries whose positions shifted the most are highlighted.

Table 6.1. Ranking (R) of South African estuaries in terms of Conservation Importance Score (in order of ranking), calculated on the basis of size (S), zonal type rarity (Z), habitat importance (H) and the updated biodiversity importance score (B).

Estuary	S	H	Z	B	IMP	R
Knysna	100	100	100	100	100	1
Olifants	100	100	90	98.0	98.5	2
Berg (Groot)	100	100	90	97.5	98.4	3
Orange (Gariep)	100	100	90	92.0	97.0	4
Kosi	100	100	70	100	97.0	5
St Lucia	100	100	70	98.5	96.6	6
Swartvlei	100	100	70	98.0	96.5	7
Bot/Kleinmond	100	100	70	97.0	96.3	8
Klein	100	100	70	95.5	95.9	9
Mhlathuze	100	100	80	82.0	93.5	10
Durban Bay	90	100	80	92.5	92.1	11
Swartkops	100	100	20	100	92.0	12
Great Fish	100	100	20	98.0	91.5	13
Mfolozi	90	100	70	93.5	91.4	14
Mngazana	100	100	30	92.5	91.1	15
Gamtoos	100	100	20	95.5	90.9	16
Keiskamma	100	100	20	95.5	90.9	17
Keurbooms	100	90	20	95.0	88.3	18
Breë	100	90	20	89.0	86.8	19
Kromme	100	90	20	87.5	86.4	20
Mlalazi	90	90	30	95.5	85.4	21
Mpekweni	90	100	10	89.0	84.3	22
Duiwenhoks	100	90	20	76.5	83.6	23
Heuningnes	90	90	20	92.0	83.5	24
Mbashe	90	90	30	86.0	83.0	25
Mtata	90	90	30	86.0	83.0	26
Wilderness	90	70	70	88.0	82.5	27
Kariega	90	80	20	97.0	82.3	28
Mtati	90	100	10	80.0	82.0	29
Mgwalana	90	100	10	76.0	81.0	30
Mzimvubu	90	90	30	78.0	81.0	31
Kowie	90	80	20	90.0	80.5	32
Xora	90	80	30	85.5	80.4	33
Goukou	90	90	20	77.5	79.9	34
Bushmans	100	60	20	91.0	79.8	35
Nxaxo/Ngqusi	90	80	10	89.0	79.3	36
Matigulu/Nyoni	90	70	30	89.0	78.8	37
Mzimkulu	80	100	30	74.5	78.6	38
Wildevoëlvlei	80	90	60	69.5	77.9	39
Great Kei	100	70	20	73.5	77.9	40
Sundays	90	70	20	87.5	77.4	41
Mzamba	80	80	30	88.5	77.1	42
Zinkwasi	80	90	10	83.5	76.4	43
Sand	90	70	10	87.0	76.3	44
Kabeljous	90	80	10	75.0	75.8	45
Gourits	90	60	20	90.0	75.5	46
Groot Brak	90	80	10	73.5	75.4	47
Seekoei	90	80	10	73.5	75.4	48
Uilskraals	80	90	10	79.0	75.3	49
Mtentu	70	80	30	94.0	74.5	50
Mgeni	70	90	10	88.0	73.5	51
Mkomazi	80	60	30	91.5	72.9	52
Mdloti	80	90	10	69.0	72.8	53
Kleinemond Wes	80	90	10	68.0	72.5	54
Kleinemond Oos	70	90	10	84.0	72.5	55
Tugela/Thukela	80	50	70	82.0	72.0	56
Verlorenvlei	70	70	60	80.0	71.5	57
Qora	80	70	20	79.5	71.4	58
Bira	80	70	10	82.5	71.1	59
Riet	80	80	10	71.5	70.9	60
Nahoon	80	60	20	87.5	70.9	61
Piesang	80	80	10	71.0	70.8	62
Tyolomnqa	80	60	10	89.0	70.3	63
Mtakatye	90	70	30	54.5	70.1	64
Rietvlei/Diep	100	10	60	85.5	69.9	65
Mdumbi	80	60	30	77.5	69.4	66
Richard's Bay	100	0	80	85.0	69.3	67
Mhlanga	80	70	10	71.0	68.3	68
Goukamma	100	40	10	67.0	67.8	69
Mhlali	60	90	10	80.0	67.5	70
Mntafufu	60	70	30	90.0	67.0	71
Mbotyi	70	70	10	80.0	66.5	72
Qinira	80	70	10	63.0	66.3	73
Cefane	80	80	10	52.0	66.0	74
Nqabara	90	70	20	40.0	65.5	75
Qolora	60	90	10	70.5	65.1	76
Hartenbos	70	60	10	82.0	64.5	77
Palmiet	70	60	20	75.5	63.9	78
Gqunube	70	50	20	83.5	63.4	79
Mdlotane	60	90	10	63.5	63.4	80
Tongati	70	80	10	54.5	62.6	81
Groot (Wes)	70	50	10	83.5	62.4	82
Mtamvuna	80	50	10	66.0	62.0	83
Kasuka	70	70	10	59.5	61.4	84
Fafa	70	80	10	47.0	60.8	85
Kwelera	70	60	20	60.5	60.1	86
Buffalo	80	40	20	62.5	59.6	87
Sipingo	30	100	10	86.0	59.5	88
Mvoti	60	30	70	83.5	59.4	89
Lovu	40	80	10	86.0	58.5	90
Gqutywa	70	70	10	47.5	58.4	91
Kwenxura	70	50	10	67.5	58.4	92
Klein Brak	80	10	10	90.0	58.0	93
Sout (Oos)	70	50	20	61.5	57.9	94
Onrus	70	60	10	53.5	57.4	95
Mnenu	80	60	10	37.5	57.4	96
Ntlonyane	70	50	10	61.0	56.8	97
Cintsa	70	50	10	59.5	56.4	98
Msikaba	50	50	30	83.0	56.3	99
Nhlabane	50	50	70	66.5	56.1	100
Quko	70	40	10	68.0	56.0	101
Bulura	70	50	10	57.5	55.9	102
Mgwegwe	40	80	10	73.0	55.3	103
Boknes	60	50	10	70.5	55.1	104
Old woman's	60	50	10	70.0	55.0	105
Kiwane	60	70	10	50.0	55.0	106

Estuary	S	H	Z	B	IMP	R
Msimbazi	50	50	10	86.0	55.0	107
Gxulu	70	50	10	52.0	54.5	108
Kobonqaba	60	50	20	64.0	54.5	109
Mtonga	70	50	10	51.0	54.3	110
Mtana	50	70	10	62.5	54.1	111
Umhlangankulu	40	80	10	62.5	52.6	112
Bloukrans	70	10	50	66.5	52.1	113
Mzintlava	60	50	30	50.5	52.1	114
Mtwalume	60	50	10	57.5	51.9	115
Umgababa	50	60	10	63.0	51.8	116
Noera	60	50	10	56.5	51.6	117
Nkodusweni	70	40	10	49.5	51.4	118
Mnyameni	60	40	30	57.5	51.4	119
Shixini	60	40	20	61.0	51.3	120
Manzimtoti	30	70	10	82.5	51.1	121
Mbizana	40	70	10	64.0	50.5	122
Zotsha	30	80	10	70.0	50.5	123
Nonoti	60	60	10	42.0	50.5	124
Ngqinisa	50	60	10	54.5	49.6	125
Lwandile	60	40	10	58.5	49.6	126
Gxara	60	40	10	58.0	49.5	127
Mpenjati	40	50	10	80.0	49.5	128
Ngqwara	60	40	10	56.0	49.0	129
Bulungula	60	40	10	55.5	48.9	130
Mgobezeleni	10	80	70	68.0	48.0	131
Gqunqe	60	40	10	48.5	47.1	132
Mtentweni	30	80	10	56.5	47.1	133
Sezela	40	50	10	70.0	47.0	134
Coega (Ngcura)	40	40	10	79.5	46.9	135
Ku-Mpenzu	50	60	10	43.5	46.9	136
Mzumbe	50	50	10	53.5	46.9	137
Buffels (Oos)	50	30	10	72.0	46.5	138
Van Stadens	60	30	10	55.0	46.3	139
Mzinto	30	80	10	51.0	45.8	140
Nkanya	50	50	10	48.5	45.6	141
Morgan	60	30	10	51.5	45.4	142
Bululo	50	30	10	66.5	45.1	143
Mahlongwana	30	80	10	48.0	45.0	144
Mendu	60	40	10	39.0	44.8	145
Mngazi	50	20	10	74.5	44.6	146
Mhlabatshane	20	90	10	52.5	44.6	147
Siyaya	30	60	10	66.5	44.6	148
Nyara	50	40	10	54.0	44.5	149
Cebe	50	40	10	54.0	44.5	150
Mpande	50	30	10	62.5	44.1	151
Mncwasa	60	20	10	55.5	43.9	152
Sinangwana	50	30	10	61.5	43.9	153
Bilanhlolo	20	60	10	79.5	43.9	154
Ku-Bhula/Mbhany.	30	70	10	52.5	43.6	155
Rooiels	40	40	10	65.0	43.3	156
Sikombe	40	50	10	53.0	42.8	157
Goda	50	30	10	56.0	42.5	158
Mbokodweni	30	40	10	76.5	42.1	159
Silvermine	30	50	10	65.0	41.8	160
Mlazazana	20	80	10	51.0	41.8	161
Ngadla	50	30	10	49.5	40.9	162
Intshambili	20	80	10	45.5	40.4	163
Nenga	40	30	10	62.5	40.1	164

Estuary	S	H	Z	B	IMP	R
Kwa-Makosi	20	90	10	33.0	39.8	165
Mkweni	30	60	10	46.5	39.6	166
Sandlundlu	30	40	10	65.0	39.3	167
Mapuzi	50	30	10	42.0	39.0	168
Mkozi	30	30	10	73.0	38.8	169
Tongazi	10	70	10	64.5	38.6	170
Eerste	40	40	10	45.0	38.3	171
Lourens	30	30	10	71.0	38.3	172
Damba	20	90	10	26.5	38.1	173
Storms	60	10	50	24.5	37.6	174
Ngogwane	40	30	10	51.0	37.3	175
Mahlongwa	30	40	10	55.5	36.9	176
Houtbaai	10	50	90	42.5	36.1	177
Little Manzimtoti	10	80	10	44.0	36.0	178
Mtentwana	40	20	10	54.5	35.6	179
Mpambanyoni	20	50	10	55.5	35.4	180
Maitland	10	70	10	49.0	34.8	181
Sihlontlweni/Gcini	40	20	10	51.0	34.8	182
Mpako	50	30	10	24.5	34.6	183
Hluleka/Majusini	50	30	10	24.5	34.6	184
Mhlungwa	20	60	10	41.0	34.3	185
Mtendwe	40	40	10	25.5	33.4	186
Mhlangeni	20	40	10	57.0	33.3	187
Seteni	10	80	10	31.0	32.8	188
Ngoma/Kobule	40	40	10	19.0	31.8	189
Mcantsi	40	20	10	38.5	31.6	190
Maalgate	50	10	10	32.0	31.5	191
Lupatana	20	40	10	49.5	31.4	192
Mtambane	40	20	10	37.0	31.3	193
Koshwana	10	80	10	24.5	31.1	194
Blue Krans	20	30	10	58.0	31.0	195
Ratel	40	10	10	45.5	30.9	196
Mzimpunzi	30	20	10	51.0	30.8	197
Lottering	50	10	50	12.5	30.6	198
Ngane	10	40	10	60.5	30.1	199
Zalu	40	20	10	32.0	30.0	200
Ncizele	30	10	10	57.5	29.9	201
Krom	10	10	60	68.5	29.6	202
Lwandilana	40	20	10	30.5	29.6	203
Sir Lowry's Pass	20	20	10	62.0	29.5	204
Jujura	30	10	10	56.0	29.5	205
Mpahlane	30	10	10	55.5	29.4	206
Mgwetyana	20	10	10	69.5	28.9	207
Kwanyana	30	10	10	51.0	28.3	208
Kaaimans	30	10	20	44.0	27.5	209
Mnamfu	10	80	10	10.0	27.5	210
Kongweni	10	40	10	48.5	27.1	211
Ntlupeni	30	10	10	44.0	26.5	212
Boboyi	10	40	10	44.0	26.0	213
Blind	10	10	10	73.5	25.9	214
Blinde	10	10	10	73.0	25.8	215
Kaba	20	40	10	25.0	25.3	216
Mpahlanyana	20	10	10	52.5	24.6	217
Mbango	10	60	10	18.0	24.5	218
Elandsbos	30	10	50	18.5	24.1	219
Matjies/Bitou	10	10	10	63.5	23.4	220
Mvuzi	10	50	10	23.0	23.3	221
Rufane	10	10	10	62.0	23.0	222

Estuary	S	H	Z	B	IMP	R
Mhlangamkulu	30	10	10	30.0	23.0	223
Mzimayi	10	40	10	31.0	22.8	224
Kandandhlovu	20	20	10	34.5	22.6	225
Mkumbane	10	40	10	29.5	22.4	226
Hickman's	30	10	10	27.0	22.3	227
Haga-haga	20	20	10	32.0	22.0	228
Tsitsikamma	10	20	10	47.0	21.8	229
Vungu	10	30	10	32.5	20.6	230
Noetsie	30	10	10	18.5	20.1	231
Ku-amanzimuz	20	20	10	24.0	20.0	232
Mlele	20	10	10	32.0	19.5	233
Groot (Oos)	10	10	50	31.0	19.3	234
Cwili	10	10	10	44.5	18.6	235
Steenbras	20	10	20	24.0	18.5	236
Klipdrif	10	10	10	44.0	18.5	237
Lilyvale	20	10	10	25.5	17.9	238
Ku-boboyi	10	20	10	31.0	17.8	239
Myekane	20	10	10	23.5	17.4	240
Mdesingane	10	30	10	16.5	16.6	241
Elands	10	10	50	18.0	16.0	242
Cunge	10	10	10	31.5	15.4	243
Bokramspruit	10	10	60	10.0	15.0	244
Schuster	10	10	60	10.0	15.0	245
Hlozi	10	10	10	28.0	14.5	246
Zolwane	10	20	10	18.0	14.5	247
Uvuzana	10	20	10	18.0	14.5	248
Mvutshini	10	20	10	16.5	14.1	249
Gwaing	10	10	10	24.5	13.6	250
Klipdrifsfontein	10	10	10	24.0	13.5	251
Hlaze	10	10	10	18.5	12.1	252
Shelbertsstroom	10	0	10	25.0	11.3	253
Ross' Creek	10	0	10	25.0	11.3	254
Klein Palmiet	10	0	10	12.0	8.0	255
Slang	10	0	10	11.5	7.9	256

Table 6.2. Ranking (R) of South African estuaries (<u>ordered from west to east</u>) in terms of Conservation Importance Score, calculated on the basis of size (S), zonal type rarity (Z), habitat importance (H) and the updated biodiversity importance score (B)

Estuary	S	H	Z	B	IMP	R
Orange (Gariep)	100	100	90	92.0	97.0	4
Olifants	100	100	90	98.0	98.5	2
Verlorenvlei	70	70	60	80.0	71.5	57
Berg (Groot)	100	100	90	97.5	98.4	3
Rietvlei/Diep	100	10	60	85.5	69.9	65
Houtbaai	10	50	90	42.5	36.1	177
Wildevoëlvlei	80	90	60	69.5	77.9	39
Bokramspruit	10	10	60	10.0	15.0	244
Schuster	10	10	60	10.0	15.0	245
Krom	10	10	60	68.5	29.6	202
Silvermine	30	50	10	65.0	41.8	160
Sand	90	70	10	87.0	76.3	44
Eerste	40	40	10	45.0	38.3	171
Lourens	30	30	10	71.0	38.3	172
Sir Lowry's Pass	20	20	10	62.0	29.5	204
Steenbras	20	10	20	24.0	18.5	236
Rooiels	40	40	10	65.0	43.3	156
Buffels (Oos)	50	30	10	72.0	46.5	138
Palmiet	70	60	20	75.5	63.9	78
Bot/Kleinmond	100	100	70	97.0	96.3	8
Onrus	70	60	10	53.5	57.4	95
Klein	100	100	70	95.5	95.9	9
Uilskraals	80	90	10	79.0	75.3	49
Ratel	40	10	10	45.5	30.9	196
Heuningnes	90	90	20	92.0	83.5	24
Klipdrifsfontein	10	10	10	24.0	13.5	251
Breë	100	90	20	89.0	86.8	19
Duiwenhoks	100	90	20	76.5	83.6	23
Goukou	90	90	20	77.5	79.9	34
Gourits	90	60	20	90.0	75.5	46
Blinde	10	10	10	73.0	25.8	215
Hartenbos	70	60	10	82.0	64.5	77
Klein Brak	80	10	10	90.0	58.0	93
Groot Brak	90	80	10	73.5	75.4	47
Maalgate	50	10	10	32.0	31.5	191
Gwaing	10	10	10	24.5	13.6	250
Kaaimans	30	10	20	44.0	27.5	209
Wilderness	90	70	70	88.0	82.5	27
Swartvlei	100	100	70	98.0	96.5	7
Goukamma	100	40	10	67.0	67.8	69
Knysna	100	100	100	100	100	1
Noetsie	30	10	10	18.5	20.1	231
Piesang	80	80	10	71.0	70.8	62
Keurbooms	100	90	20	95.0	88.3	18
Matjies/Bitou	10	10	10	63.5	23.4	220
Sout (Oos)	70	50	20	61.5	57.9	94
Groot (Wes)	70	50	10	83.5	62.4	82
Bloukrans	70	10	50	66.5	52.1	113
Lottering	50	10	50	12.5	30.6	198
Elandsbos	30	10	50	18.5	24.1	219
Storms	60	10	50	24.5	37.6	174
Elands	10	10	50	18.0	16.0	242
Groot (Oos)	10	10	50	31.0	19.3	234
Tsitsikamma	10	20	10	47.0	21.8	229

Estuary	S	H	Z	B	IMP	R
Klipdrif	10	10	10	44.0	18.5	237
Slang	10	0	10	11.5	7.9	256
Kromme	100	90	20	87.5	86.4	20
Seekoei	90	80	10	73.5	75.4	48
Kabeljous	90	80	10	75.0	75.8	45
Gamtoos	100	100	20	95.5	90.9	16
Van Stadens	60	30	10	55.0	46.3	139
Maitland	10	70	10	49.0	34.8	181
Swartkops	100	100	20	100	92.0	12
Coega (Ngcura)	40	40	10	79.5	46.9	135
Sundays	90	70	20	87.5	77.4	41
Boknes	60	50	10	70.5	55.1	104
Bushmans	100	60	20	91.0	79.8	35
Kariega	90	80	20	97.0	82.3	28
Kasuka	70	70	10	59.5	61.4	84
Kowie	90	80	20	90.0	80.5	32
Rufane	10	10	10	62.0	23.0	222
Riet	80	80	10	71.5	70.9	60
Kleinemond Wes	80	90	10	68.0	72.5	54
Kleinemond Oos	70	90	10	84.0	72.5	55
Klein Palmiet	10	0	10	12.0	8.0	255
Great Fish	100	100	20	98.0	91.5	13
Old woman's	60	50	10	70.0	55.0	105
Mpekweni	90	100	10	89.0	84.3	22
Mtati	90	100	10	80.0	82.0	29
Mgwalana	90	100	10	76.0	81.0	30
Bira	80	70	10	82.5	71.1	59
Gqutywa	70	70	10	47.5	58.4	91
Blue Krans	20	30	10	58.0	31.0	195
Mtana	50	70	10	62.5	54.1	111
Keiskamma	100	100	20	95.5	90.9	17
Ngqinisa	50	60	10	54.5	49.6	125
Kiwane	60	70	10	50.0	55.0	106
Tyolomnqa	80	60	10	89.0	70.3	63
Shelbertsstroom	10	0	10	25.0	11.3	253
Lilyvale	20	10	10	25.5	17.9	238
Ross' Creek	10	0	10	25.0	11.3	254
Ncera	60	50	10	56.5	51.6	117
Mlele	20	10	10	32.0	19.5	233
Mcantsi	40	20	10	38.5	31.6	190
Gxulu	70	50	10	52.0	54.5	108
Goda	50	30	10	56.0	42.5	158
Hlozi	10	10	10	28.0	14.5	246
Hickman's	30	10	10	27.0	22.3	227
Buffalo	80	40	20	62.5	59.6	87
Blind	10	10	10	73.5	25.9	214
Hlaze	10	10	10	18.5	12.1	252
Nahoon	80	60	20	87.5	70.9	61
Qinira	80	70	10	63.0	66.3	73
Gqunube	70	50	20	83.5	63.4	79
Kwelera	70	60	20	60.5	60.1	86
Bulura	70	50	10	57.5	55.9	102
Cunge	10	10	10	31.5	15.4	243
Cintsa	70	50	10	59.5	56.4	98
Cefane	80	80	10	52.0	66.0	74
Kwenxura	70	50	10	67.5	58.4	92
Nyara	50	40	10	54.0	44.5	149

Estuary	S	H	Z	B	IMP	R
Haga-haga	20	20	10	32.0	22.0	228
Mtendwe	40	40	10	25.5	33.4	186
Quko	70	40	10	68.0	56.0	101
Morgan	60	30	10	51.5	45.4	142
Cwili	10	10	10	44.5	18.6	235
Great Kei	100	70	20	73.5	77.9	40
Gxara	60	40	10	58.0	49.5	127
Ngogwane	40	30	10	51.0	37.3	175
Qolora	60	90	10	70.5	65.1	76
Ncizele	30	10	10	57.5	29.9	201
Kobonqaba	60	50	20	64.0	54.5	109
Nxaxo/Ngqusi	90	80	10	89.0	79.3	36
Cebe	50	40	10	54.0	44.5	150
Gqunqe	60	40	10	48.5	47.1	132
Zalu	40	20	10	32.0	30.0	200
Ngqwara	60	40	10	56.0	49.0	129
Sihlontlweni/Gcini	40	20	10	51.0	34.8	182
Qora	80	70	20	79.5	71.4	58
Jujura	30	10	10	56.0	29.5	205
Ngadla	50	30	10	49.5	40.9	162
Shixini	60	40	20	61.0	51.3	120
Nqabara	90	70	20	40.0	65.5	75
Ngoma/Kobule	40	40	10	19.0	31.8	189
Mendu	60	40	10	39.0	44.8	145
Mbashe	90	90	30	86.0	83.0	25
Ku-Mpenzu	50	60	10	43.5	46.9	136
Ku-Bhula/Mbhan.	30	70	10	52.5	43.6	155
Ntlonyane	70	50	10	61.0	56.8	97
Nkanya	50	50	10	48.5	45.6	141
Xora	90	80	30	85.5	80.4	33
Bulungula	60	40	10	55.5	48.9	130
Ku-amanzimuz.	20	20	10	24.0	20.0	232
Mncwasa	60	20	10	55.5	43.9	152
Mpako	50	30	10	24.5	34.6	183
Nenga	40	30	10	62.5	40.1	164
Mapuzi	50	30	10	42.0	39.0	168
Mtata	90	90	30	86.0	83.0	26
Mdumbi	80	60	30	77.5	69.4	66
Lwandilana	40	20	10	30.5	29.6	203
Lwandile	60	40	10	58.5	49.6	126
Mtakatye	90	70	30	54.5	70.1	64
Hluleka/Majusini	50	30	10	24.5	34.6	184
Mnenu	80	60	10	37.5	57.4	96
Mtonga	70	50	10	51.0	54.3	110
Mpande	50	30	10	62.5	44.1	151
Sinangwana	50	30	10	61.5	43.9	153
Mngazana	100	100	30	92.5	91.1	15
Mngazi	50	20	10	74.5	44.6	146
Bululo	50	30	10	66.5	45.1	143
Mtambane	40	20	10	37.0	31.3	193
Mzimvubu	90	90	30	78.0	81.0	31
Ntlupeni	30	10	10	44.0	26.5	212
Nkodusweni	70	40	10	49.5	51.4	118
Mntafufu	60	70	30	90.0	67.0	71
Mzintlava	60	50	30	50.5	52.1	114
Mzimpunzi	30	20	10	51.0	30.8	197
Mbotyi	70	70	10	80.0	66.5	72

Estuary	S	H	Z	B	IMP	R
Mkozi	30	30	10	73.0	38.8	169
Myekane	20	10	10	23.5	17.4	240
Lupatana	20	40	10	49.5	31.4	192
Mkweni	30	60	10	46.5	39.6	166
Msikaba	50	50	30	83.0	56.3	99
Mgwegwe	40	80	10	73.0	55.3	103
Mgwetyana	20	10	10	69.5	28.9	207
Mtentu	70	80	30	94.0	74.5	50
Sikombe	40	50	10	53.0	42.8	157
Kwanyana	30	10	10	51.0	28.3	208
Mnyameni	60	40	30	57.5	51.4	119
Mpahlanyana	20	10	10	52.5	24.6	217
Mpahlane	30	10	10	55.5	29.4	206
Mzamba	80	80	30	88.5	77.1	42
Mtentwana	40	20	10	54.5	35.6	179
Mtamvuna	80	50	10	66.0	62.0	83
Zolwane	10	20	10	18.0	14.5	247
Sandlundlu	30	40	10	65.0	39.3	167
Ku-boboyi	10	20	10	31.0	17.8	239
Tongazi	10	70	10	64.5	38.6	170
Kandandhlovu	20	20	10	34.5	22.6	225
Mpenjati	40	50	10	80.0	49.5	128
Umhlangankulu	40	80	10	62.5	52.6	112
Kaba	20	40	10	25.0	25.3	216
Mbizana	40	70	10	64.0	50.5	122
Mvutshini	10	20	10	16.5	14.1	249
Bilanhlolo	20	60	10	79.5	43.9	154
Uvuzana	10	20	10	18.0	14.5	248
Kongweni	10	40	10	48.5	27.1	211
Vungu	10	30	10	32.5	20.6	230
Mhlangeni	20	40	10	57.0	33.3	187
Zotsha	30	80	10	70.0	50.5	123
Boboyi	10	40	10	44.0	26.0	213
Mbango	10	60	10	18.0	24.5	218
Mzimkulu	80	100	30	74.5	78.6	38
Mtentweni	30	80	10	56.5	47.1	133
Mhlangamkulu	30	10	10	30.0	23.0	223
Damba	20	90	10	26.5	38.1	173
Koshwana	10	80	10	24.5	31.1	194
Intshambili	20	80	10	45.5	40.4	163
Mzumbe	50	50	10	53.5	46.9	137
Mhlabatshane	20	90	10	52.5	44.6	147
Mhlungwa	20	60	10	41.0	34.3	185
Mfazazana	20	80	10	51.0	41.8	161

Estuary	S	H	Z	B	IMP	R
Kwa-Makosi	20	90	10	33.0	39.8	165
Mnamfu	10	80	10	10.0	27.5	210
Mtwalume	60	50	10	57.5	51.9	115
Mvuzi	10	50	10	23.0	23.3	221
Fafa	70	80	10	47.0	60.8	85
Mdesingane	10	30	10	16.5	16.6	241
Sezela	40	50	10	70.0	47.0	134
Mkumbane	10	40	10	29.5	22.4	226
Mzinto	30	80	10	51.0	45.8	140
Mzimayi	10	40	10	31.0	22.8	224
Mpambanyoni	20	50	10	55.5	35.4	180
Mahlongwa	30	40	10	55.5	36.9	176
Mahlongwana	30	80	10	48.0	45.0	144
Mkomazi	80	60	30	91.5	72.9	52
Ngane	10	40	10	60.5	30.1	199
Umgababa	50	60	10	63.0	51.8	116
Msimbazi	50	50	10	86.0	55.0	107
Lovu	40	80	10	86.0	58.5	90
Little Manzimtoti	10	80	10	44.0	36.0	178
Manzimtoti	30	70	10	82.5	51.1	121
Mbokodweni	30	40	10	76.5	42.1	159
Sipingo	30	100	10	86.0	59.5	88
Durban Bay	90	100	80	92.5	92.1	11
Mgeni	70	90	10	88.0	73.5	51
Mhlanga	80	70	10	71.0	68.3	68
Mdloti	80	90	10	69.0	72.8	53
Tongati	70	60	10	54.5	62.6	81
Mhlali	60	90	10	80.0	67.5	70
Seteni	10	80	10	31.0	32.8	188
Mvoti	60	30	70	83.5	59.4	89
Mdlotane	60	90	10	63.5	63.4	80
Nonoti	60	60	10	42.0	50.5	124
Zinkwasi	80	90	10	83.5	76.4	43
Tugela/Thukela	80	50	70	82.0	72.0	56
Matigulu/Nyoni	90	70	30	89.0	78.8	37
Siyaya	30	60	10	66.5	44.6	148
Mlalazi	90	90	30	95.5	85.4	21
Mhlathuze	100	100	80	82.0	93.5	10
Richard's Bay	100	0	80	85.0	69.3	67
Nhlabane	50	50	70	66.5	56.1	100
Mfolozi	90	100	70	93.5	91.4	14
St Lucia	100	100	70	98.5	96.6	6
Mgobezeleni	10	80	70	68.0	48.0	131
Kosi	100	100	70	100	97.0	5

7. THE WAY FORWARD

This study has attended to some of the main criticisms of the estuary importance ratings. However, it has not been able to address all issues. While RDM practitioners can have much greater confidence in the updated ratings, there is still room for further improvement in future. Future studies should address the following needs:

1. Completion of the habitat area and total area estimates for all estuaries. This includes checking the existing area data in cases where there are doubts about accuracy. It would be particularly useful if the estuaries were digitized in a geographic information system (GIS).
2. Sampling of invertebrates from a lot more systems. This would improve the accuracy of the models produced in this study, and would also provides useful baseline data for future RDM assessments, especially rapid or desktop assessments.
3. An in depth study of the trade-off between sampling effort and data quality for estuarine fishes, allowing an evaluation of the Harrison data used in the index versus use of other more comprehensive data-sets, and implications for the fish importance rating.
4. A total recount of birds of all the South African estuaries to update the counts which are mostly over 20 years old.
5. A sensitivity analysis of the weightings in the importance index. Testing of the index is needed, to investigate the effects of, for example, only retaining the biotic elements, or reducing the weighting of the zonal type rarity index.

Other related WRC reports available:

Resource monitoring procedures for estuaries: For application in the ecological reserve determination and implementation process.

Taljaard S; van Niekerk L; Huizinga P; Joubert W

Monitoring of water resources is required under the NWA, but some methods still need to be developed. Monitoring of the ecological Reserve in estuaries is a case in point, and the aim of this project is to develop resource monitoring procedures to establish the status of the estuaries and to monitor the response to the RDM once implemented. Monitoring is necessary to provide feedback to the ongoing management of individual estuaries, but more importantly to refine and increase confidence in Reserve determinations. Personnel will also be trained to do the work. This project links to the estuary management programme

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